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OPPD
Omaha Public Power District

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May 14, 2005
LIC-05-0057

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

References:
1. Docket No. 50-285
2. Letter from Samuel J. Collins (NRC) to Ross Ridenoure (OPPD) dated February 11, 2003, Issuance of Order Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors (EA-03-009) (NRC-03-025) (ML030380470)
3. Letter from R. William Borchardt (NRC) to Ross Ridenoure (OPPD) dated February 20, 2004, Issuance of First Revised NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors (NRC-04-0022) (ML040220181)
4. Letter from Ralph L. Phelps (OPPD) to Document Control Desk (NRC) dated April 7, 2005, Fort Calhoun Station Unit No. 1, Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors (LIC-05-0040) (ML050980052)
5. Letter from Ralph L. Phelps (OPPD) to Document Control Desk (NRC) dated April 19, 2005, Fort Calhoun Station Unit No. 1, Supplemental Information for Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors (LIC-05-0043) (ML051050581)
6. Letter from Ralph L. Phelps (OPPD) to Document Control Desk (NRC) dated April 19, 2005, Fort Calhoun Station Unit No. 1, Additional Information for Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors (LIC-05-0048) (ML051100064)

SUBJECT: Fort Calhoun Station Unit No. 1, Revised Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors

On February 11, 2003, the NRC issued Reference 2 for interim inspection requirements for reactor pressure vessel (RPV) heads at pressurized water reactor (PWR) facilities. On

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February 20, 2004, the NRC issued the Reference 3, which superseded Reference 2. Reference 3 modified the requirements regarding nondestructive examination of the penetration nozzles.

The Omaha Public Power District (OPPD) submitted References 4 and 5 for Fort Calhoun Station Unit No. 1 (FCS), anticipating that some relaxation from the requirements of Reference 3 would be required for the Spring 2005 Refueling Outage (RFO). Based on inspection results obtained to date, OPPD provides the attached relaxation request that supersedes the Reference 4 and 5request.

As discussed with Nuclear Reactor Regulation (NRR) personnel of the NRC staff in a phone conversation on April 29, 2005, and pursuant to the procedure specified in Section IV, paragraph F, of Reference 3, OPPD requests relaxation from the requirements specified in Section IV, Paragraph C.(5)(b)(ii) for Fort Calhoun Station Unit No. 1 (FCS) for certain Control Element Drive Mechanism (CEDM) nozzles for which eddy current testing requirements cannot be completed as required. Specifically, OPPD requests relaxation for portions of the wetted surface of the nozzle base material for certain CEDM nozzles. The specific areas of the CEDM nozzles for which relaxation is requested are described in Attachment 1.

Relaxation for certain areas of the CEDM and In-Core Instrumentation (ICI) nozzles was requested in References 4and 5; however, the relaxation requested for the ICI nozzles is no longer required. Relaxation requested for the CEDM nozzles in References 4 and 5 is superseded by this revised relaxation request.

Based on the inspection results for all RPV head penetration nozzles, OPPD is submitting this relaxation request for certain CEDM nozzles described in Attachment 1. Attachment 2 contains a Report on Flaw Evaluation for Fort Calhoun Upper Head Penetrations. Please note that Reference 1 of Attachment 2 has already been submitted to the NRC by Reference 6.

The Spring 2005 Refueling Outage for FCS began on February 26, 2005. The current schedule for plant criticality is May 25, 2005. Therefore, OPPD requests that the NRC complete its review and approval of this relaxation request by May 25, 2005.

This letter contains the following commitments:

1. OPPD will complete the inspections required by Reference 3 as modified by this relaxation request and will provide the results of these inspections to the NRC within 60 days of returning the plant to operation.

2. If the NRC staff finds that the crack-growth formula in industry report MRP-55 is unacceptable, OPPD shall revise its analysis that justifies relaxation of Reference 3 within 30 days after the NRC informs OPPD of an NRC-approved crack growth formula. If OPPD's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end of the current operating cycle, this relaxation is rescinded and OPPD shall, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack

growth acceptance criteria are exceeded during the subsequent operating cycle, OPPD shall, within 30 days, submit the revised analysis for NRC review. If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the current operating cycle or the subsequent operating cycle, OPPD shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack-growth analyses performed for this and future cycles for RPV head penetrations must be based on an acceptable crack growth rate formula.

3. OPPD will replace the FCS RPV head during the Fall 2006 RFO.

If you have any questions or require additional information, please contact Thomas R. Byrne at (402) 533-7368.

Sincerely,

R. L. Phelps 5-14-05

Ralph L. Phelps
Division Manager
Nuclear Engineering

RLP/TRB/trb

Attachment 1 - Revised Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors

Attachment 2 - Westinghouse Letter CFTC-05-54, Report on Flaw Evaluation for Fort Calhoun Upper Head Penetrations, May 2005

Attachment 1

Revised Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors

Attachment 1

Revised Relaxation Request for First Revised Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors

1. **ASME Code Component(s) Affected**

The scope of this relaxation includes the Fort Calhoun Station Unit No. 1 (FCS) ASME Class 1 reactor pressure vessel (RPV) head penetrations as delineated in Table 1 and Figures 1 through 5. The Omaha Public Power District (OPPD) has determined its primary water stress corrosion cracking (PWSCC) susceptibility category for the 2005 Spring Refueling Outage (RFO) to be "High" per the guidance in Reference 1, Sections 1V.A and 1V.B.

2. **Applicable Examination Requirements**

The NRC issued Reference 1 establishing interim inspection requirements for RPV heads of pressurized water reactors. Section IV, Paragraph C (Parts 1, 2, 3, and 4), require nonvisual nondestructive examination (NDE) in accordance with Section IV, Paragraph C.(5)(b). Section IV.C.(5)(b) of Reference 1 states the following:

"(b) For each penetration, perform a nonvisual NDE in accordance with either (i), (ii), or (iii):

(i) Ultrasonic testing of the RPV head penetration nozzle volume (i.e., Nozzle base material from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 2 inches [see Figure IV-1]); OR from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.0-inch below the lowest point at the toe of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level (including all residual and normal operation stresses) of 20 ksi tension and greater (see Figure IV-2). In addition, an assessment shall be made to determine if leakage has occurred into the annulus between the RPV head penetration nozzle and the RPV head low-alloy steel.

(ii) Eddy current testing or dye penetrant testing of the entire wetted surface of the J-groove weld and the wetted surface of the RPV head penetration nozzle base material from at least 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 2 inches [see Figure IV-3]); OR from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.0-inch below the lowest point at the toe of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level (including all residual and normal operation stresses) of 20 ksi tension and greater (see Figure IV-4).

(iii) A combination of (i) and (ii) to cover equivalent volumes, surfaces and leak paths of the RPV head penetration nozzle base material and J-groove weld as described in (i) and (ii). Substitution of a portion of a volumetric exam on a nozzle with a surface examination may be performed with the following requirements:

1. On nozzle material below the J-groove weld, both the outside diameter and inside diameter surfaces of the nozzle must be examined.

2. On nozzle material above the J-groove weld, surface examination of the inside diameter surface of the nozzle is permitted provided a surface examination of the J-groove weld is also performed."

3. Requirement from Which Relaxation is Requested

OPPD currently has examined RPV head penetrations in accordance with Reference 1, Section IV.C(5)(b)(ii), which states:

"Eddy current testing or dye penetrant testing of the entire wetted surface of the J-groove weld and the wetted surface of the RPV head penetration nozzle base material from at least 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 2 inches [see Figure IV-3]); OR from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.0 inch below the lowest point at the toe of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level (including all residual and normal operation stresses) of 20 ksi tension and greater (see Figure IV-4)."

Specifically, the inspection for FCS includes the following:

Eddy current testing (ECT) of the entire wetted surface of the J-groove weld and the wetted surface of the RPV head penetration nozzle base material from at least 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis or the bottom of the nozzle if less than 2 inches (see Reference 1, Figure IV-3).

OPPD has employed a wetted surface ECT examination methodology for inspections of RPV head penetration nozzles. The wetted surface has been examined by using three different probe holders for examination of different surfaces: a J-groove holder, a blade holder, and a fingertip holder. The probe holders incorporate an eddy current sensor which applies an alternating current magnetic field to interrogate for material surface discontinuities. Auto-biasing controls maintain sensor sensitivity in varying residual magnetic fields resulting from delta-ferrites in the RPV head cladding heat-affected zone. Examination results are evaluated in accordance with guidance in ASME Section V, Article 8.

Examination results that exceed flaw criteria specified by Reference 1 are being remediated or repaired in accordance with ASME Section XI, 1998 edition, 2000 addendum. Flaws in penetration nozzles or J-groove weld surface areas will be removed and repaired as necessary to maintain primary boundary integrity.

OPPD has performed upper surface bare metal visual examinations of the RPV head during the three most recent refueling outages (2002, 2003, and 2005). No reportable indications were found during any of these inspections.

4. Reason for Relaxation Request

During the performance of the FCS RPV head inspection in the Spring 2005 RFO, OPPD discovered that some of the concentrically designed CEDM nozzles and thermal sleeves were not aligned per design drawings, preventing probe access to some of the CEDM nozzle inner diameter (ID) areas (Figure 6). The blade-type ECT nozzle probe was designed to be inserted in the annulus between the CEDM nozzle and thermal sleeve for ID examination of the nozzle base material. The examination methodology incorporates an overlapping series of axial scans around the circumference of each nozzle. The CEDM nozzles appear to be slightly warped because of heat stresses from the initial welding process during construction of the RPV head. Due to the resulting off-center location of the thermal sleeves relative to the nozzles, the space between the nozzle and the thermal sleeve is insufficient in some places for probe insertion. OPPD developed a special tool to enable the thermal sleeves to be moved enough for probe insertion (Figure 7). This enabled access to most of the ID areas blocked by the off-center thermal sleeves. However, some ID areas for certain CEDM penetration nozzles were still inaccessible even when using the special tool, due to the need to limit the amount of force exerted by the special tool to protect the structural integrity of the thermal sleeves. The inspected areas of the ID of each CEDM nozzle for which relaxation is requested are depicted in the attached figures, which are designated by penetration number.

Additional attempts were made to scan the ID areas blocked by the thermal sleeves with some success. However, CEDM nozzle 25 remains problematic. CEDM nozzle 25 has a circumferential area of approximately 80° that could not be scanned due to lack of clearance between the thermal sleeve and the nozzle for the probe. As with all of the other nozzles, this nozzle was washed in an attempt to remove any potential boron or deposited crud, and the pusher tool was used on it at the maximum allowable pressure in an effort to open up the thermal sleeve to nozzle gap but these efforts were not successful on this nozzle. Further efforts to open up this gap were deemed to be undesirable without causing significant damage to the thermal sleeve. This results in the inability to achieve full 360° coverage for CEDM nozzle 25 (See appropriate Figure). Therefore relaxation is requested for the area of CEDM nozzle 25 as summarized on Table 1 and shown on the appropriate Figure.

Most of the remaining required CEDM nozzle ID areas have been inspected, in some cases through multiple scanning attempts with the use of the special tool. However, three overlapping issues (in addition to CEDM nozzle 25) have arisen that prevent full 100 percent inspection of the CEDM nozzle ID areas, even when using the special tool. These areas also require relaxation from Reference 1 and are discussed below. Table 1 summarizes the areas for which relaxation is requested as shown on the appropriate Figures.

1. <u>Lack of Vertical Scan Coverage</u> – Some CEDM penetration nozzles have a small area (generally less than 0.25 inches) at the top of the axial scan area that was not covered due to random constraints on axial travel. Generally, these areas do not extend the full circumference around each nozzle. These constraints were due to either mechanical clearance between the thermal sleeve and the nozzle, or hard deposits possibly from boron or crud buildup in the nozzle to thermal sleeve gap. This resistance caused probe travel stoppage when forces met allowable limits intended to protect probe integrity. This issue affects CEDM penetration nozzles 6, 7, 8, 10, 12, 14, 19, 22, 23, 24, 26, 28, 29, 30, 31, 32, 33, 34, 35, 37, 38, 39, 40, and 41 as shown on the appropriate Figures.

2. <u>CEDM Thermal Sleeve Tab Interference</u> - A small portion of the wetted surface of the RPV head penetration nozzle base material above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) is not accessible by the ECT device in some CEDM penetrations. Each thermal sleeve has four, 0.125 inch wide by 0.25 inch high centering tabs on its outer surface, spaced 90 degrees apart. Probe insertion was limited whenever the end of the blade contacted a tab. This prevented scanning above that height for the combined width of the blade and tab (approximately 0.56 inch) at specified tab locations in affected penetrations (see Figures 5 and 6). Full-height scanning was accomplished between the centering tabs where there is no interference between tabs and the probe. Circumferential orientation of the tabs relative to weld high and low points is variable because the thermal sleeves are not keyed in the nozzles. The distance from the lower end of each thermal sleeve to its centering tabs is fixed. As hillside angle increases, the vertical distance decreases between centering tabs and the J-groove weld root. Manufacturing tolerance stack-up combines with lack of as-built nozzle assembly measurements to make actual distances uncertain. Centering tabs intrude into the required inspection zone (less than 2 inches above the plane perpendicular to the nozzle axis at the highest point of the root of the J-groove weld). This affects CEDM penetration nozzles 22, 23, 26, 28, 30, 31, 32, 33, 34, 35, 37, 38, 39, 40, and 41 as shown on the appropriate Figures.

3. <u>Mechanical Limits of Probe Delivery System</u> – Mechanical limitations in probe travel (at 8.00 inches) occurred due to the addition on the probe delivery mechanism of the special tool needed to apply sufficient force on the thermal sleeves. This prevented full axial coverage at the top of the circumferential scan area. This is shown on Figure 8. The probe delivery mechanism was originally designed to allow full coverage of the area. However, the nozzle examination areas made accessible only through use of the special tool were significantly larger than the areas made

inaccessible by its use. This affects CEDM penetration nozzles 38, 39, 40, and 41 as shown on the appropriate Figures.

Various CEDM nozzles have single missing scan line information in some areas. OPPD has determined in each case that a single missing scan line does not prevent determination of a potential significant flaw, due to the amount of overlap of adjacent scan line coverage in adjacent eddy current traces. An indication picked up in one scan line will also be seen by the adjacent scan lines. A missing scan line is most likely caused by small boron deposits or crud accumulation on the nozzle or thermal sleeve surface which causes axial travel resistance on the probe. Due to features in the scanning mechanism that prevent the probe delivery device from exceeding allowed force limits (intended to prevent probe failure during the scan), the probe automatically retracts when sufficient resistance is detected and begins to scan the next line. These areas are considered to be fully inspected.

Therefore, OPPD requests relaxation from portions of the examination described in Section 3 for the specific CEDM ID areas discussed in Table 1 and as illustrated in the appropriate Figures. Relaxation is requested for areas on 25 CEDM penetration nozzles. The total area represented by this relaxation is a very small part of the completed examination area. Except as stated herein, all other required wetted portions of the CEDM head penetration nozzle base material and J-groove weld surfaces have been examined or are being examined as originally planned.

There has been no difficulty in examining the Incore Instrumentation (ICI) nozzles or the reactor head vent. No repairs are required to be performed prior to returning the plant to operation.

5. Proposed Alternative and Basis for Use

OPPD requests relaxation from portions of the examination described in Section 3 above for the specific areas discussed in Table 1 and as illustrated in the appropriate Figures. Westinghouse has performed deterministic fracture mechanics analysis, based upon the Dominion Engineering elastic plastic analysis, to evaluate stresses in the nozzles for which relaxation is requested (Attachment 2). A reactor head temperature of 588°F was used for the calculations (Reference 2). This analysis establishes that the scope of relaxation requested will not significantly affect the continued safe operation of the RPV head for one additional fuel cycle, after which it will be replaced. Additionally, crack growth analysis in Attachment 2 indicates that nozzle ejection is an unlikely scenario and that leakage would occur prior to ejection. This indicates a robust safety margin exists with respect to the single cycle of operation that will elapse between the examination and the RPV head replacement in Fall 2006. Additionally, OPPD has performed a probabilistic fracture mechanics evaluation for the areas proposed for relaxation (Reference 3). This analysis concludes that partial inspection coverage, for an area as low as 97% of full 100% inspection coverage, appears to be acceptable, and does not result in significant differences in the probability of leakage or nozzle ejection from full 100% inspection coverage.

Supporting Capabilities for Relaxation Request

OPPD utilizes a continuous on-line reactor coolant system (RCS) leak rate calculation and leakage-monitoring program at FCS to support operating crews in early detection of changes in RCS leakage. An advanced RCS leak rate calculation method for trending a continuous three-hour RCS leak rate is utilized. Channel noise is filtered and multiple inputs are compared to produce smooth and accurate trend plots. The accuracy and stability of the data supports early detection of minor changes in the leak rate. The value of this tool was proven when control room operators identified a 0.1 gpm increase in the RCS leakage trend and were able to identify and isolate a charging pump packing leak in approximately one hour. The program also tracks daily leakage into various tanks and sumps where RCS leakage accumulates. These tank levels are plotted along a timeline with RCS leakage, which aids in explaining changes in RCS leak rate. Conservative action levels are set from baseline RCS leakages measured during hot shutdown and full power operation. Any significant penetration nozzle leaks over the next cycle prior to RPV head replacement would be manifested as unidentified RCS leakage and receive prompt attention for mitigation (including containment entry for visual inspection) by the operating crew. OPPD policy is to resolve unidentified RCS leakage when it occurs.

The FCS RPV head has forty-eight penetrations, which have nozzles made from five different heats of material (see Table 1). All of the heats of material have performed well, and none of the heats have shown any industry occurrence of PWSCC. It is also accepted that the likelihood for PWSCC increases as the yield strength exceeds 50 ksi. Only five of the forty-eight nozzles on the FCS RPV head have yield strengths in excess of 50 ksi (nozzles 11, 12, 13, 14, and 47). These five nozzles have a slightly higher chance of PWSCC (shown by the diagonal lined and dotted areas on Figure 9). However, the remaining nozzles on the FCS RPV head have yield strengths well below 50 ksi and therefore have very low probability of PWSCC (shown by the grey and white areas on Figure 9). In conclusion, based on relatively low FCS nozzle temperatures of 588°F, fabrication using Huntington Alloy 600, and relatively low yield strengths, the FCS RPV head nozzles have a generally low susceptibility to PWSCC.

Alternatives Considered to Examine Areas for Which Relaxation is Requested

OPPD has considered alternative means of examining the areas for which relaxation is requested. OPPD considers that performance of any of these alternatives would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Hardship to Scan Areas With a Lack of Vertical Scan Coverage

In order to obtain data on these very small areas, it would be necessary to essentially repeat the entire CEDM nozzle ID inspection sequence, with the associated additional radiation exposure. The EC scanner aligns to the bottom of the nozzle and the extension shaft, and scans upward in a "comb" pattern. In order to reach the very small area along the nozzle circumference at the extreme top of the inspection area 2 inches above the upper plane of the J-groove weld, shown in the figures for each affected nozzle, the entire scan area would have to be repeated for 24 nozzles. Based on our experience this outage, this would require more than six additional days of outage time and would still not allow scanning above the tabs. Additionally, the potential exists for damage to the thermal sleeves from repeated use of the special tool to move the thermal sleeves.

Hardship to Scan Areas Because of the Mechanical Limits of the Probe Delivery System

A redesign of the special tool to accommodate full extension of the probe arm would be necessary to obtain data on these very small areas. This special tool redesign would take approximately two additional days of outage time, and the affected CEDM nozzle areas would have to be rescanned, with the associated additional radiation exposure. Additionally, the potential exists for damage to the thermal sleeves from repeated use of the special tool to move the thermal sleeves.

Hardship of Shortening of Thermal Sleeves to Scan All Areas For Which Relaxation is Sought:

Full probe access to all areas of the CEDM nozzle ID would require removal of thermal sleeve centering tabs, which could only be practically accomplished by removal of part or all of the thermal sleeves. The CEDM extension shafts would have to be removed from the reactor head before thermal sleeves could be removed. A different vendor would have to be mobilized to support removal of the thermal sleeves.

OPPD has very limited space below the FCS RPV head due to the small size of the RPV head. FCS also has a unique CEDM design where the extension shafts cannot be removed with the RPV head on the storage stand. The RPV head must be raised high enough to enable CEDM extension shaft removal and reinstallation from under the RPV head, i.e., the extension shafts would have to be removed and reinstalled with the RPV head suspended. There is limited crane lifting height to raise the RPV head to allow for CEDM extension shaft removal. The RPV head would also have to be elevated over the RPV for re-installation of the CEDM extension shafts to achieve their proper alignment. A stand would need to be fabricated to hold the RPV head in place during CEDM extension shaft re-installation to prevent damage to the equipment.

Difficulty in achieving proper alignment of the CEDM extension shafts in the RPV head on reinstallation while the RPV head is suspended over the RPV is a major concern. The CEDM extension shafts are 21 feet long and the upper end is 0.875 inch in diameter. The upper end is internally and externally threaded, and slotted. The internal thread that would be used for suspending the extension shafts for removal and reinstallation is only 0.31 inch diameter and 0.5 inch minimum full thread depth. Extension shaft lower ends will not withstand accidental dropping. A re-assembly tool will require a tapered lower end. Without such a guide taper, the top of the extension shaft may hang up on the lower end of the rack during reinstallation. Excessive pulling force could break the thread and drop the extension shaft to the floor. In summary, re-assembly would be difficult, time-consuming and involve considerable risk to a reactivity control system. This evolution has never been performed at FCS or at any other nuclear power plant because this CEDM design is unique to FCS.

The examination for this outage was intended to be performed remotely with the CEDM extension shafts and thermal sleeves installed. This method was specifically selected to avoid the risks described above and the significant dose to our radiation workers. Foreign material generated by the disassembly and removal processes could potentially cause CEDM mechanical seals to leak and fail after the plant is returned to power, potentially challenging reactor coolant system (RCS) Technical Specifications leakage limits. Additionally, it is estimated that removal of thermal sleeves would consume up to 55 person-rems and extend the outage duration by up to 450 hours if all thermal sleeves for the affected CEDM penetrations require removal. Structural limitations, assembly integrity, and inadequate clearance issues have the same magnitude of difficulty whether all or one thermal sleeve is removed.

Hardship of Rotation of Thermal Sleeves to Scan All Areas For Which Relaxation is Sought:

In order to rotate the thermal sleeves to re-orient the centering tabs to allow for ID inspection of CEDM nozzles, OPPD would have to build equipment to clamp onto the nozzle and thermal sleeve to enable rotation to occur. Rotating the thermal sleeve has the potential for deforming the thermal sleeve and creating operational problems with control rod movement. Additionally, rotating the thermal sleeves could cause the centering tabs to scratch the ID of the CEDM housings and introduce artifacts which would have to be dispositioned, and potential sites for initiation of PWSCC. There is also a strong possibility that the affected thermal sleeves will not move or would not provide required clearances.

6. Duration of Proposed Alternative

This relaxation is applicable only to the Spring 2005 RFO for FCS. The FCS RPV head is scheduled for replacement in the Fall 2006 RFO.

7. Status Report of RPV Head Penetration Nozzle Examinations Completed to Date

As of May 14, 2005, OPPD has completed the inspections of all ICI nozzles (OD, ID and J-groove), the RPV head vent nozzle, and all CEDM nozzle OD, ID, and J-groove welds. Data analysis required rescanning of small areas on 11 CEDM nozzle J-groove welds to complete 100 % coverage, and this is currently in progress. No reportable indications have been found.

8. Precedents

1. Letter from Herbert N. Berkow (NRC) to Joseph E. Venable (Waterford 3) dated March 22, 2005, Relaxation Request from US Nuclear Regulatory Commission (NRC) First Revised Order EA-03-009 for Control Element Drive Mechanism (CEDM) Nozzles (TAC No. MC2643), Docket No. 50-382 (ML050820683).

2. Letter from Herbert N. Berkow (NRC) to Gregory M. Rueger (Diablo Canyon Unit 2) dated November 23, 2004, Relaxation of Requirements Associated with First Revised Order (EA-03-009) Regarding Alternate Examination Coverage for Reactor Pressure Vessel Head Penetration Nozzles (TAC No. MC4932) Docket No. 50-323 (ML043290092).

3. Letter from Stuart A. Richards (NRC) to P. E. Katz (Calvert Cliffs) dated April 18, 2003, Relaxation of the Requirements of Order (EA-03-009), Regarding Reactor Pressure Vessel Head Inspections (TAC Nos. MB7752 and MB7753), Docket Nos. 50-317 and 50-318 (ML031070434).

4. Letter from Scott W. Moore (NRC) to J. A. Stall (St. Lucie Unit 2) dated May 29, 2003, Order EA-03-009 Relaxation Requests Nos. 1 and 2 Regarding Examination Coverage of Reactor Pressure Vessel Head Penetration Nozzles (TAC Nos. MB8165 and MB8166), Docket No. 50-389 (ML031500489).

9. References

1. Letter from R. William Borchardt (NRC) to Ross Ridenoure (OPPD) dated February 20, 2004, Issuance of First Revised NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors (NRC-04-0022) (ML040220181).

2. EPRI MRP-48, PWR +Materials Reliability Program Response to NRC Bulletin 2001-01, August 2001.

3. Structural Integrity Associates Calculation FCS-10Q-301, Probabilistic Fracture Mechanics of Fort Calhoun Top Head Penetrations, May 7, 2005, Rev. 1.

Attachment 1, Table 1: Description of Fort Calhoun RPV Head Penetrations and Scope of Relaxation Requested

Penetrations		Tube Diameter, Inches		Hillside Angle, Degrees at Nozzle Centerline	Alloy 600 Tube Material		Examinations and Relaxation Requested		
Type	Numbers	OD	ID		Manufacturer, Heat No.	Yield, ksi	OD ECT	ID ECT)	J-Groove Weld ECT
CEDM	1	3.50	2.73	0.0	Huntington NX4908	37.0	Examination As Planned	Examination As Planned	Examination As Planned
CEDM	2	3.50	2.73	13.6	Huntington NX4908	37.0		Examination As Planned	
CEDM	3	3.50	2.73	13.6	Huntington NX4908	37.0		Examination As Planned	
CEDM	4	3.50	2.73	13.6	Huntington NX4908	37.0		Examination As Planned	
CEDM	5	3.50	2.73	13.6	Huntington NX4908	37.0		Examination As Planned	
CEDM	6	3.50	2.73	21.8	Huntington NX4908	37.0		**See Figure 99.01% coverage**	
CEDM	7	3.50	2.73	21.8	Huntington NX4908	37.0		**See Figure 98.62% coverage**	
CEDM	8	3.50	2.73	21.8	Huntington NX4908	37.0		**See Figure 99.38% coverage**	
CEDM	9	3.50	2.73	21.8	Huntington NX4908	37.0		Examination As Planned	
CEDM	10	3.50	2.73	21.8	Huntington NX4908	37.0		**See Figure 99.09% coverage**	
CEDM	11	3.50	2.73	21.8	Huntington NX5836	56.0		Examination As Planned	
CEDM	12	3.50	2.73	21.8	Huntington NX5836	56.0		**See Figure 99.30% coverage**	

Attachment 1, Table 1: Description of Fort Calhoun RPV Head Penetrations and Scope of Relaxation Requested									
Penetrations		Tube Diameter, Inches		Hillside Angle, Degrees at Nozzle Centerline	Alloy 600 Tube Material		Examinations and Relaxation Requested		
Type	Numbers	OD	ID		Manufacturer, Heat No.	Yield, ksi	OD ECT	ID ECT)	J-Groove Weld ECT
CEDM	13	3.50	2.73	21.8	Huntington NX5836	56.0	Examination As Planned	Examination As Planned	Examination As Planned
CEDM	14	3.50	2.73	24.6	Huntington NX5836	56.0		**See Figure 99.27% coverage**	
CEDM	15	3.50	2.73	24.6	Huntington NX5836	37.0		Examination As Planned	
CEDM	16	3.50	2.73	24.6	Huntington NX5836	37.0		Examination As Planned	
CEDM	17	3.50	2.73	24.6	Huntington NX5836	37.0		Examination As Planned	
CEDM	18	3.50	2.73	28.1	Huntington NX4908	37.0		Examination As Planned	
CEDM	19	3.50	2.73	28.1	Huntington NX4908	37.0		**See Figure 99.22% coverage**	
CEDM	20	3.50	2.73	28.1	Huntington NX4908	37.0		Examination As Planned	
CEDM	21	3.50	2.73	28.1	Huntington NX4908	37.0		Examination As Planned	
CEDM	22	3.50	2.73	36.8	Huntington NX4908	37.0		**See Figure 98.94% coverage**	
CEDM	23	3.50	2.73	36.8	Huntington NX4908	37.0		**See Figure 99.05% coverage**	
CEDM	24	3.50	2.73	36.8	Huntington NX4908	37.0		**See Figure 98.81% coverage**	

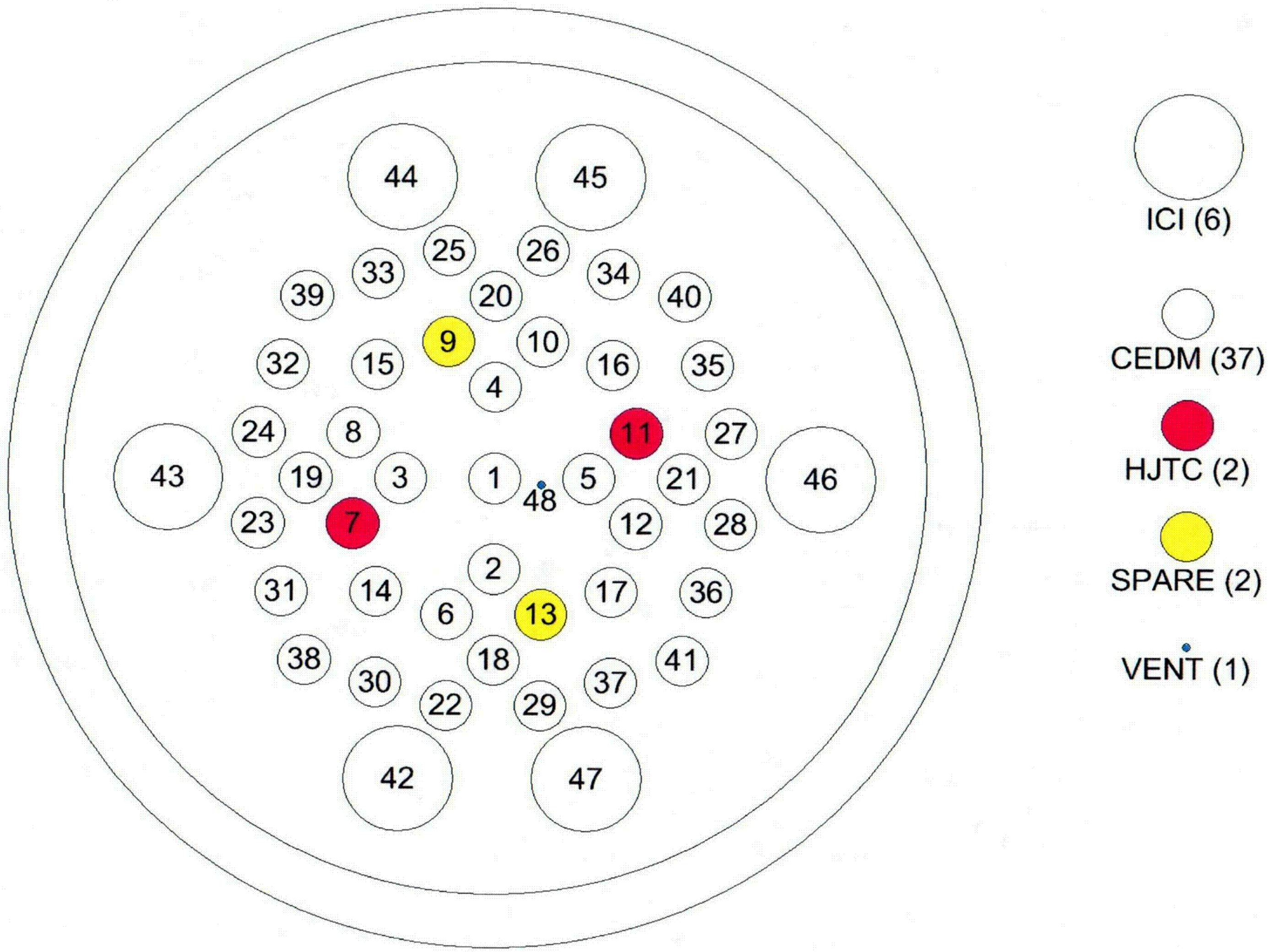
Attachment 1, Table 1: Description of Fort Calhoun RPV Head Penetrations and Scope of Relaxation Requested

Penetrations		Tube Diameter, Inches		Hillside Angle, Degrees at Nozzle Centerline	Alloy 600 Tube Material		Examinations and Relaxation Requested		
Type	Numbers	OD	ID		Manufacturer, Heat No.	Yield, ksi	OD ECT	ID ECT)	J-Groove Weld ECT
CEDM	25	3.50	2.73	36.8	Huntington NX4908	37.0	Examination As Planned	See Figure 75.18% coverage	Examination As Planned
CEDM	26	3.50	2.73	36.8	Huntington NX4908	37.0		See Figure 97.79% coverage	
CEDM	27	3.50	2.73	36.8	Huntington NX4908	37.0		Examination As Planned	
CEDM	28	3.50	2.73	36.8	Huntington NX4908	37.0		See Figure 99.18% coverage	
CEDM	29	3.50	2.73	36.8	Huntington NX4908	37.0		See Figure 99.77% coverage	
CEDM	30	3.50	2.73	37.3	Huntington NX4908	37.0		See Figure 97.34% coverage	
CEDM	31	3.50	2.73	37.3	Huntington NX4908	37.0		See Figure 99.53% coverage	
CEDM	32	3.50	2.73	37.3	Huntington NX4908	37.0		See Figure 97.76% coverage	
CEDM	33	3.50	2.73	37.3	Huntington NX4908	37.0		See Figure 96.99% coverage	
CEDM	34	3.50	2.73	37.3	Huntington NX4908	37.0		See Figure 99.12% coverage	
CEDM	35	3.50	2.73	37.3	Huntington NX4908	37.0		See Figure 99.25% coverage	
CEDM	36	3.50	2.73	37.3	Huntington NX4908	37.0		Examination As Planned	

Attachment 1, Table 1: Description of Fort Calhoun RPV Head Penetrations and Scope of Relaxation Requested

Penetrations		Tube Diameter, Inches		Hillside Angle, Degrees at Nozzle Centerline	Alloy 600 Tube Material		Examinations and Relaxation Requested		
Type	Numbers	OD	ID		Manufacturer, Heat No.	Yield, ksi	OD ECT	ID ECT)	J-Groove Weld ECT
CEDM	37	3.50	2.73	37.3	Huntington NX4908	37.0	Examination As Planned	**See Figure 99.38% coverage**	Examination As Planned
CEDM	38	3.50	2.73	41.7	Huntington NX4908	37.0		**See Figure 94.85% coverage**	
CEDM	39	3.50	2.73	41.7	Huntington NX4908	37.0		**See Figure 93.35% coverage**	
CEDM	40	3.50	2.73	41.7	Huntington NX4908	37.0		**See Figure 93.61% coverage**	
CEDM	41	3.50	2.73	41.7	Huntington NX4908	37.0		**See Figure 93.20% coverage**	
ICI	42 through 46	6.63	5.19	54.4	Huntington NX7054	32.0	Examination As Planned	Examination As Planned	Examination as planned (Relaxation requested in April 7, 2005 submittal withdrawn).
ICI	47	6.63	5.19	54.4	Huntington NX7901	52.5			
Vent	48	1.05	0.74	7.5	Huntington NX3575	41.0	Not Applicable	Examination As Planned	Examination As Planned

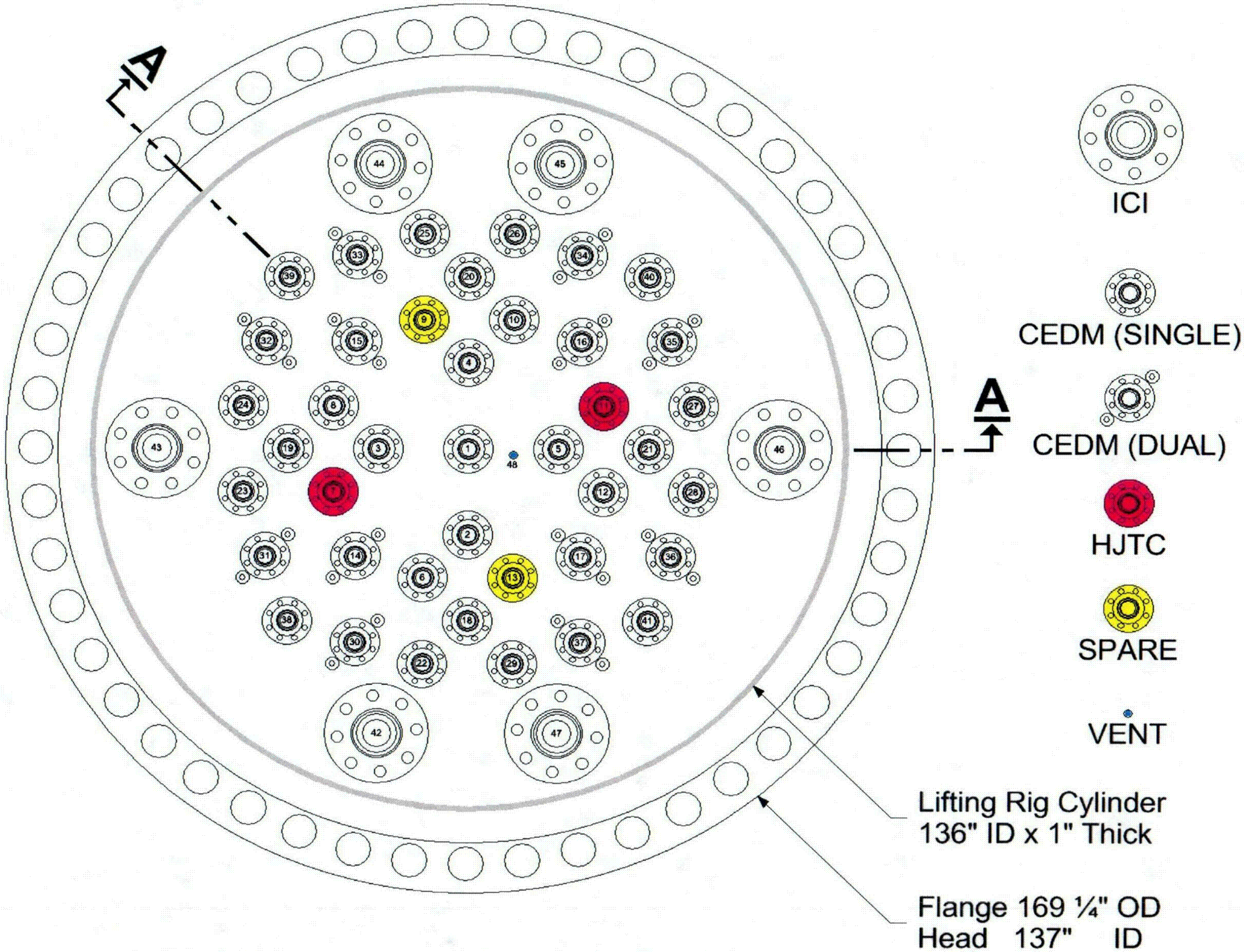
Attachment 1, Figure 1



FORT CALHOUN RVH NOZZLE MAP

C01

Attachment 1, Figure 2



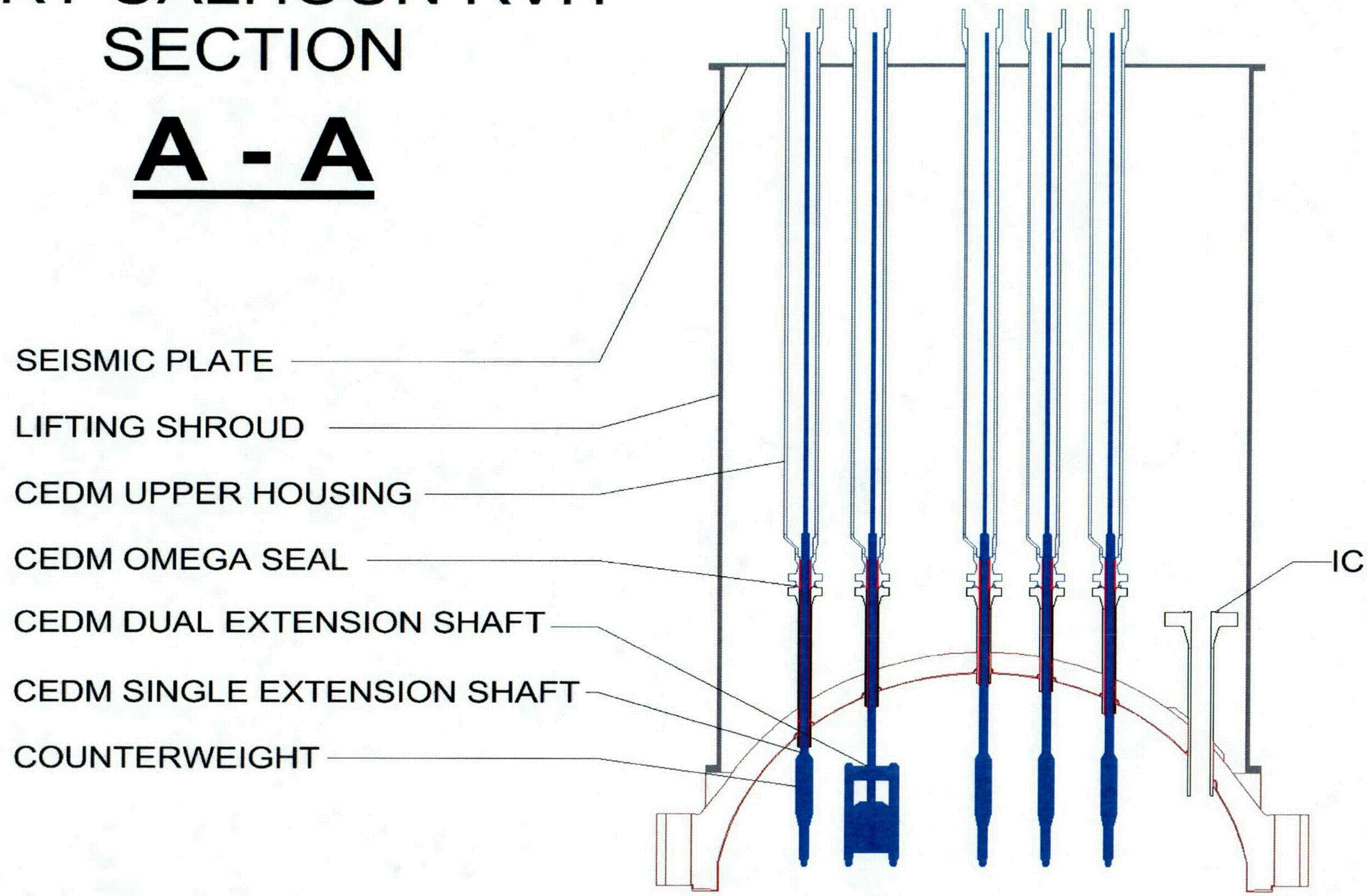
FORT CALHOUN RVH PLAN VIEW

C02

Attachment 1, Figure 3

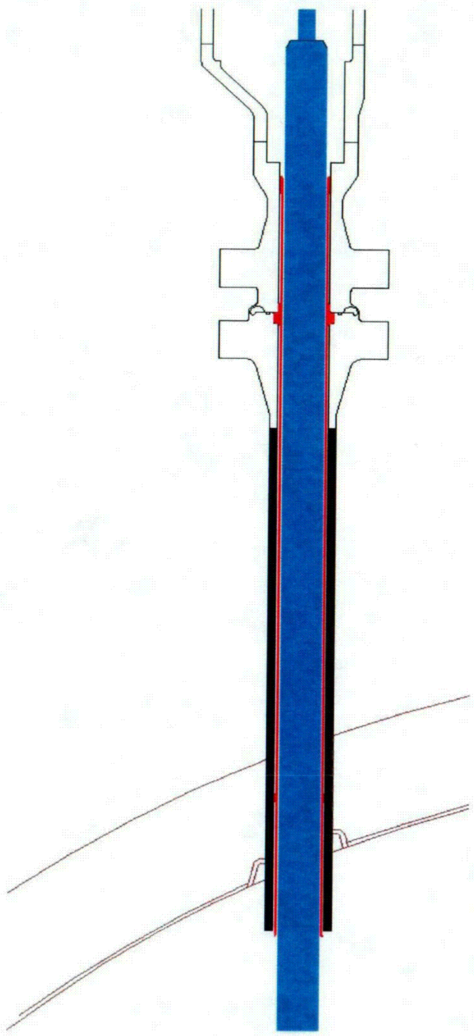
FORT CALHOUN RVH SECTION

A - A



C03

Attachment 1, Figure 4



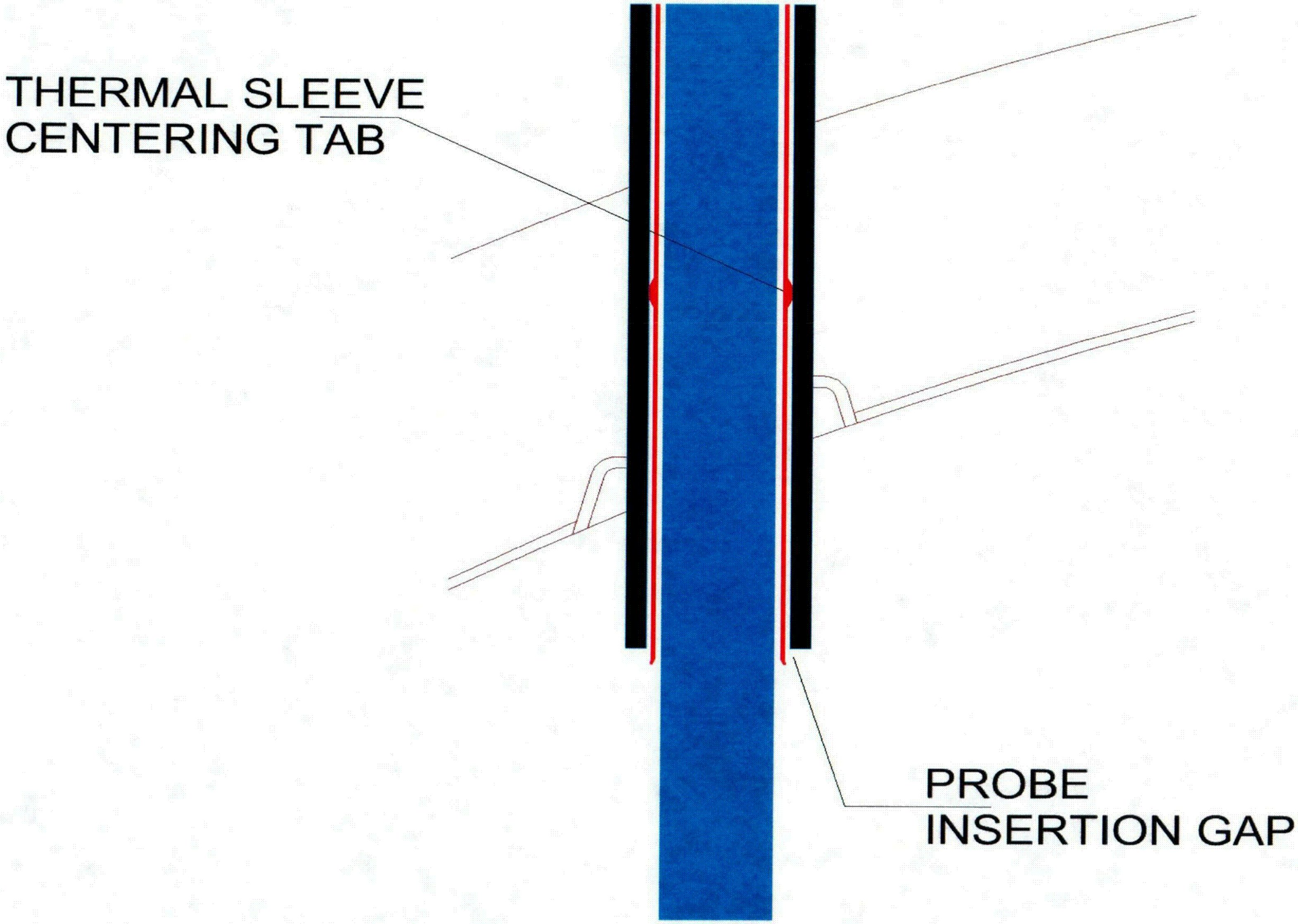
CEDM NOZZLE
3.500" OD
2.728" ID
0.386" WALL

THERMAL SLEEVE
2.500" OD
2.370" ID
0.065" WALL

GRIPPER
2.125" OD

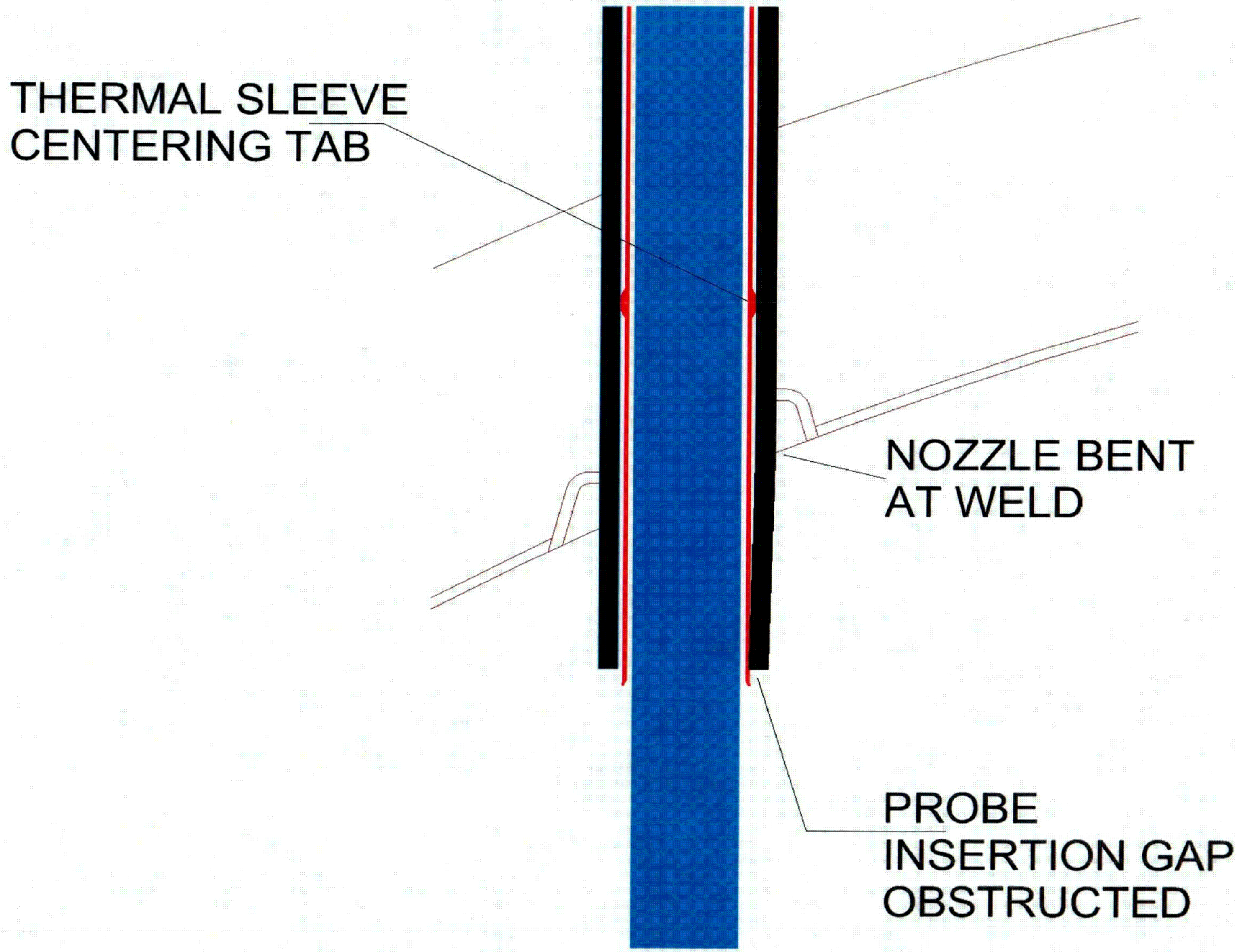
C04

Attachment 1, Figure 5



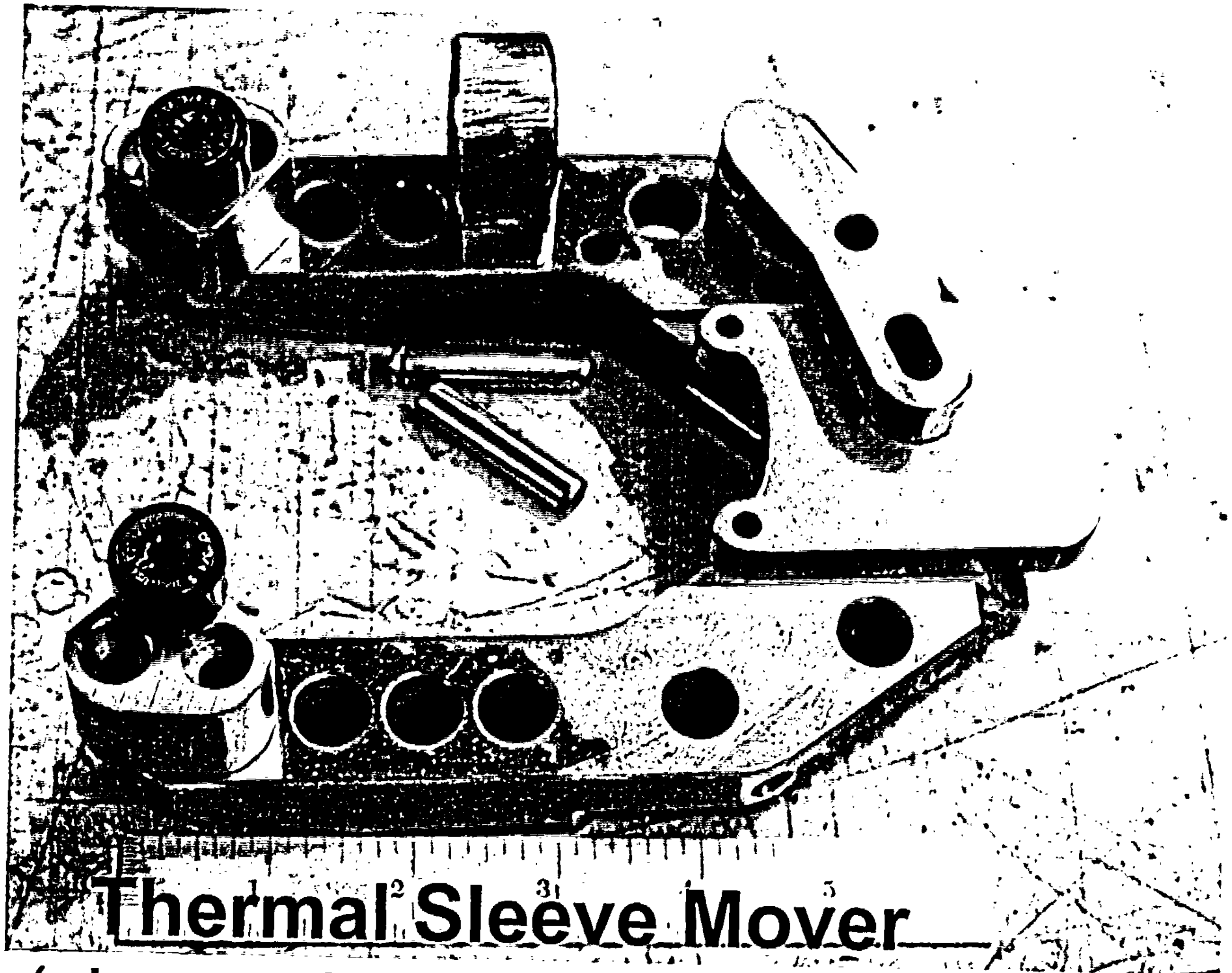
C05

Attachment 1, Figure 6



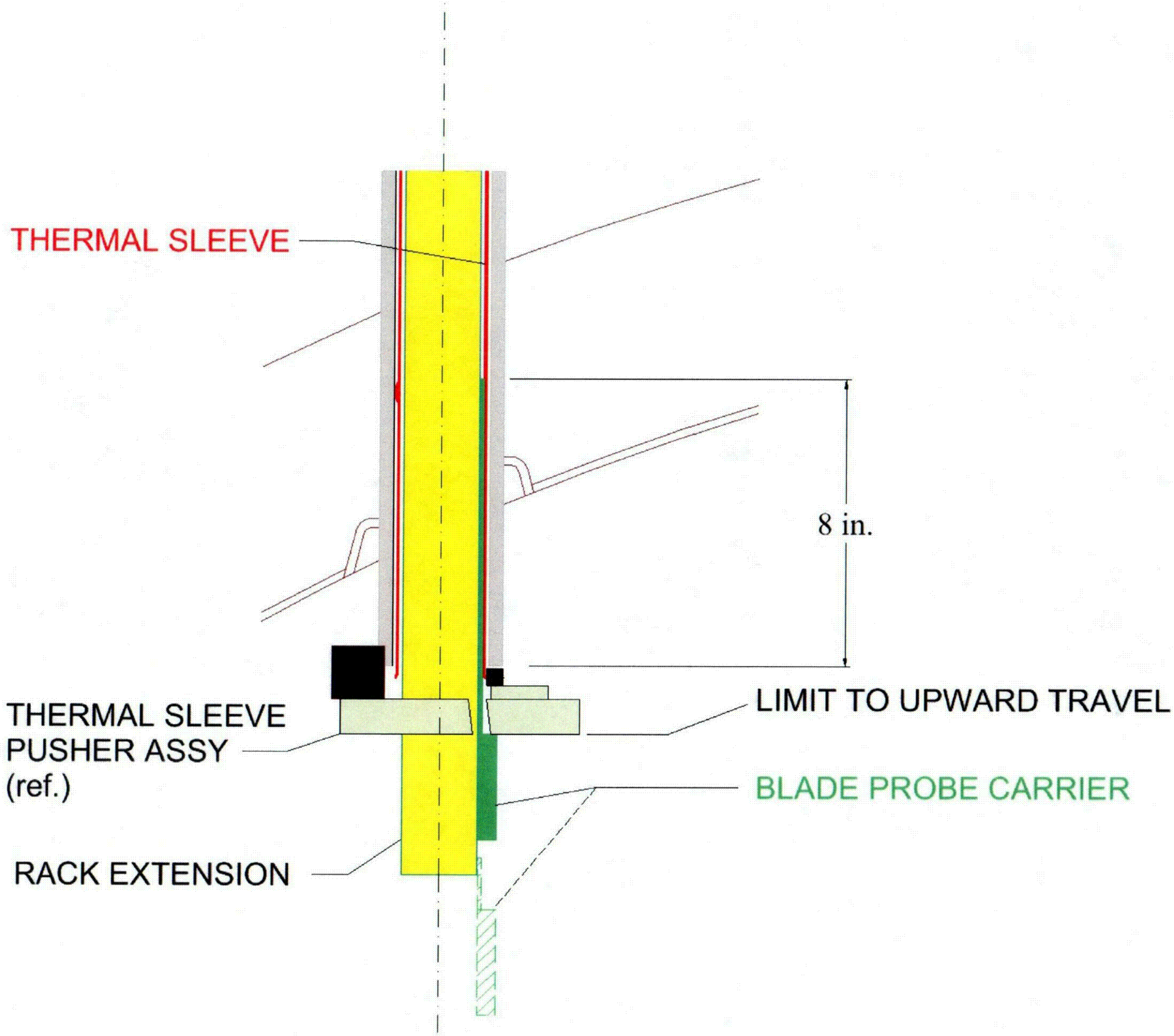
C06

Attachment 1, Figure 7



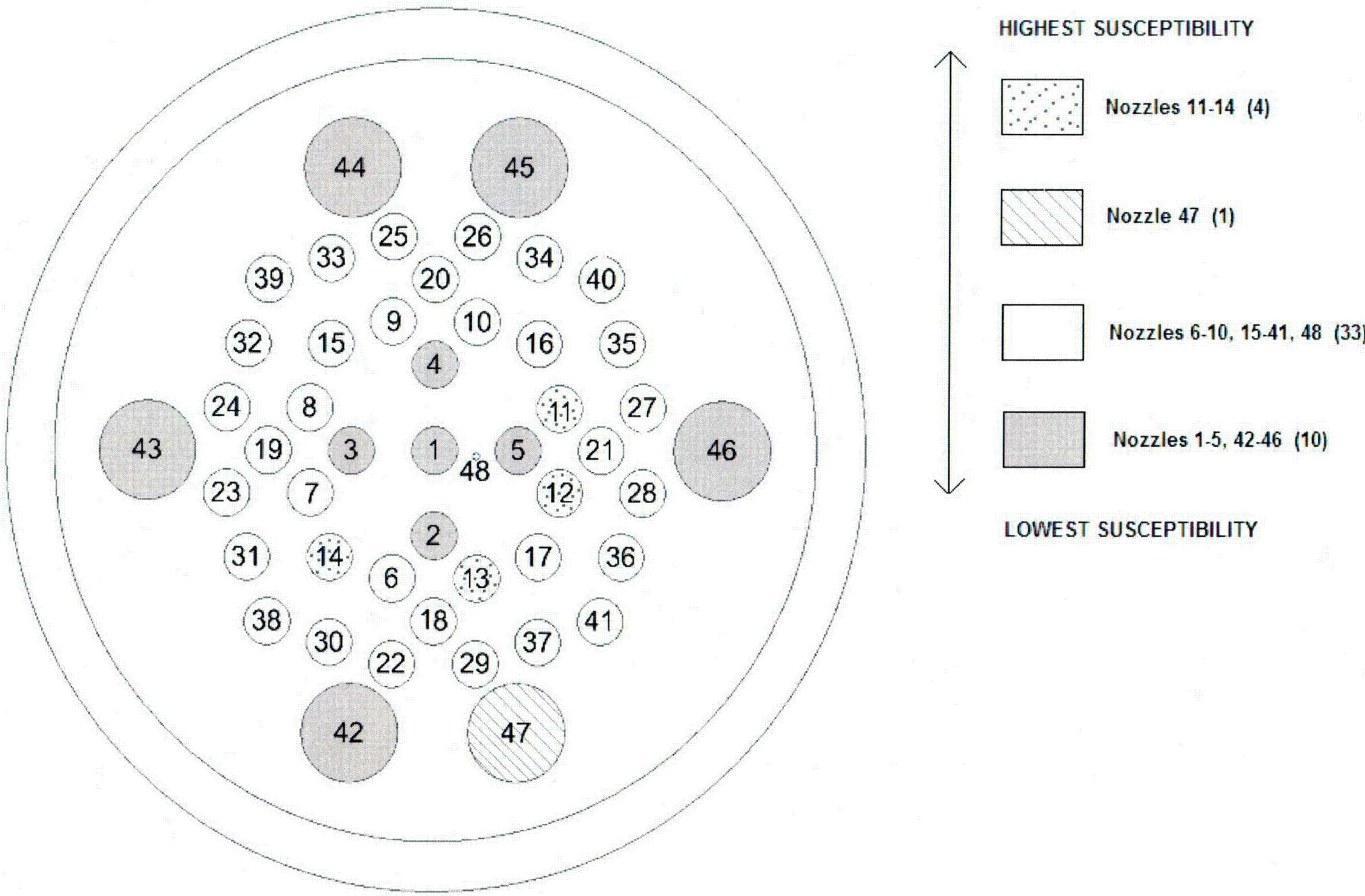
Thermal Sleeve Mover
(shown during construction)

Attachment 1, Figure 8



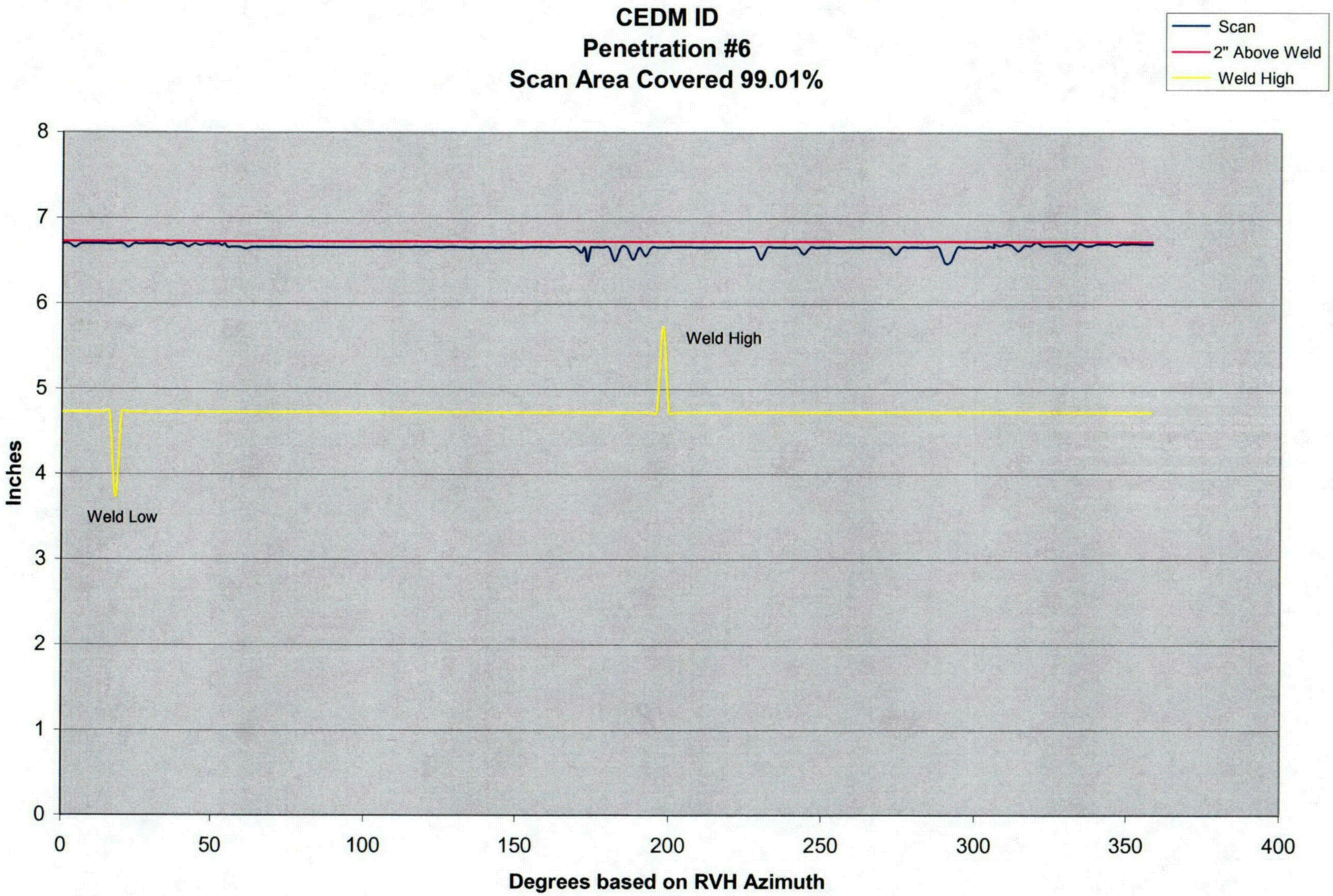
C07

Attachment 1, Figure 9

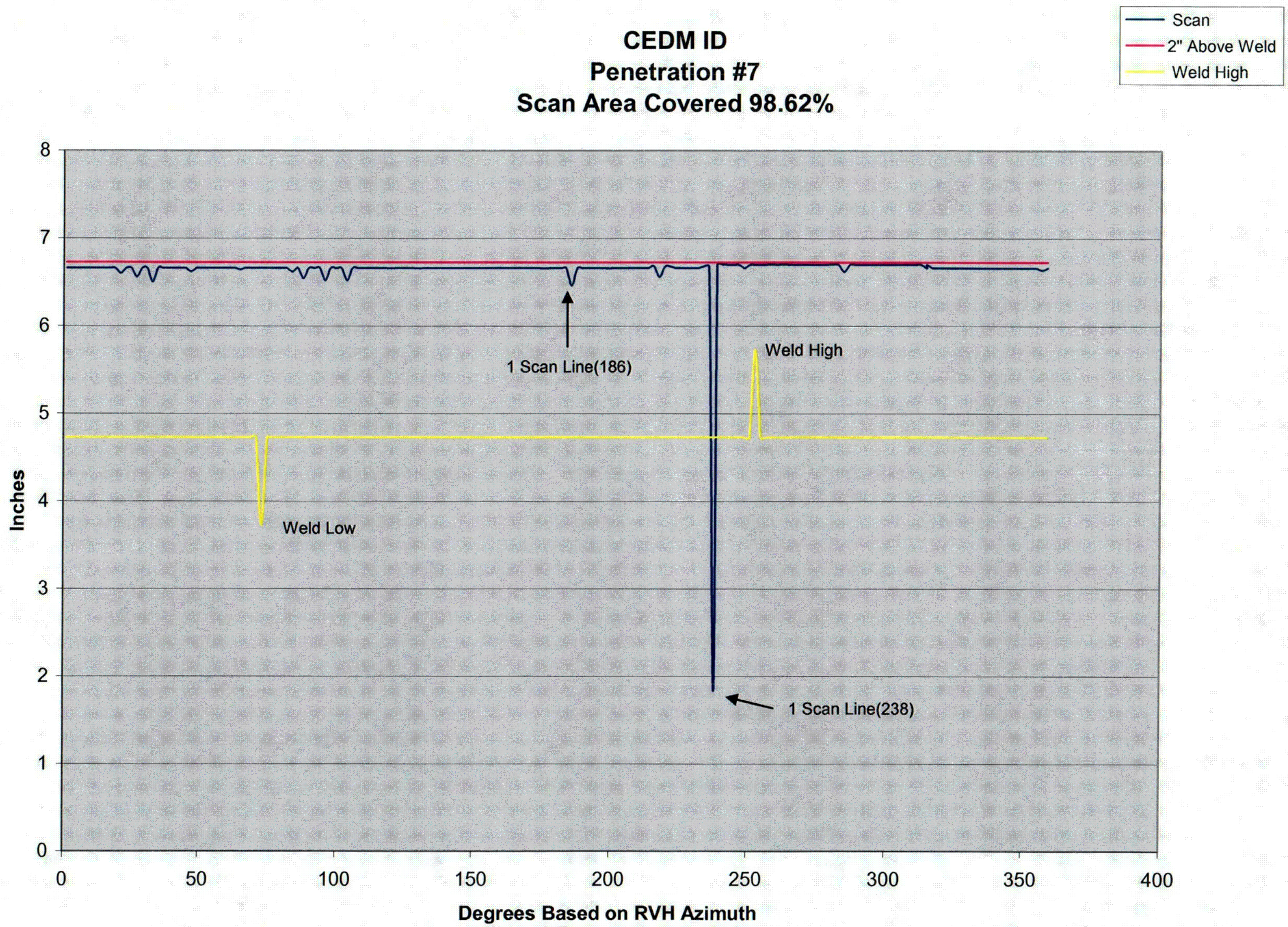


FORT CALHOUN RVH NOZZLE MATERIAL MAP

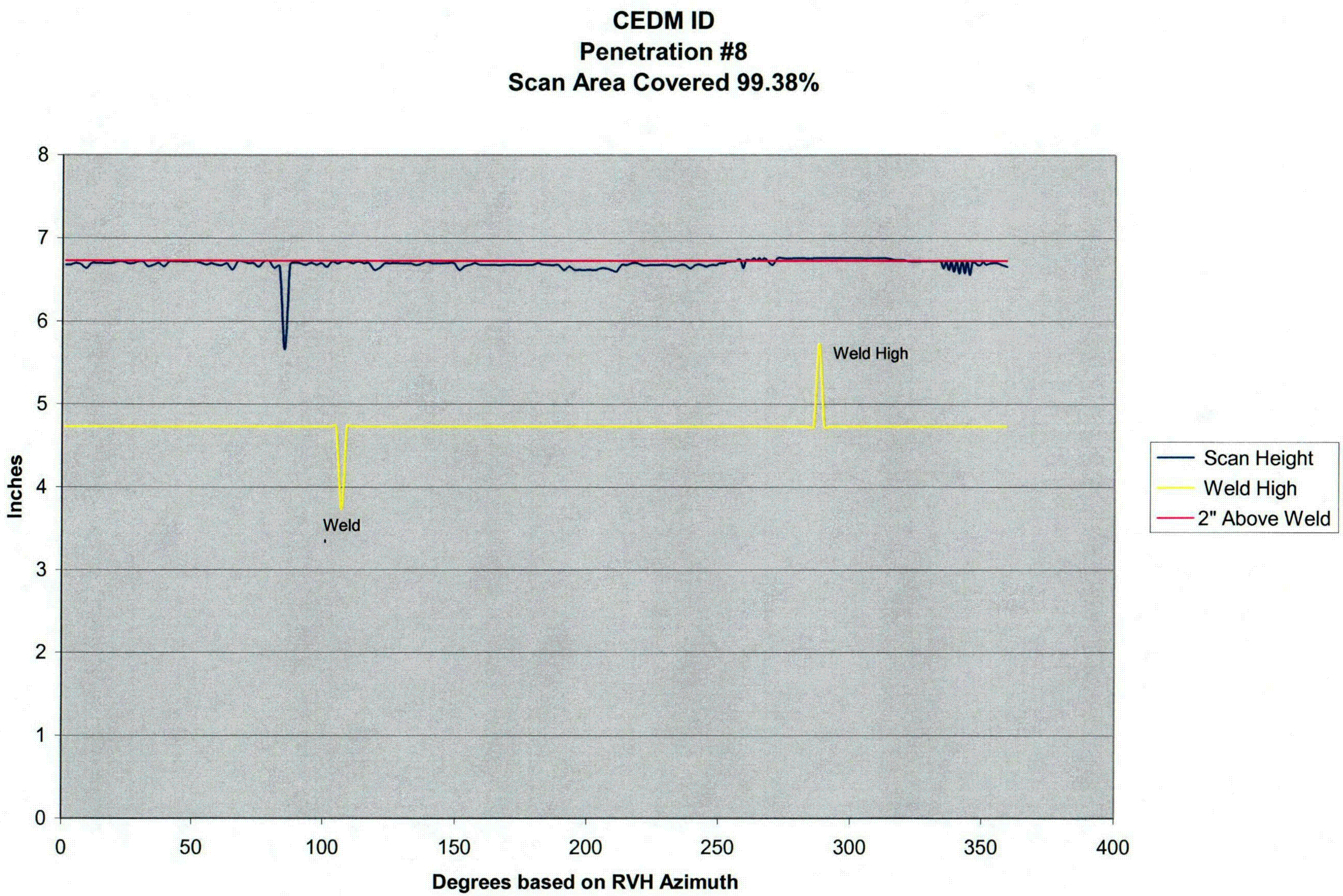
C08


CEDM ID
Penetration #6
Scan Area Covered 99.01%
Scan
2" Above Weld
Weld High
Inches
Weld High
Weld Low
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400

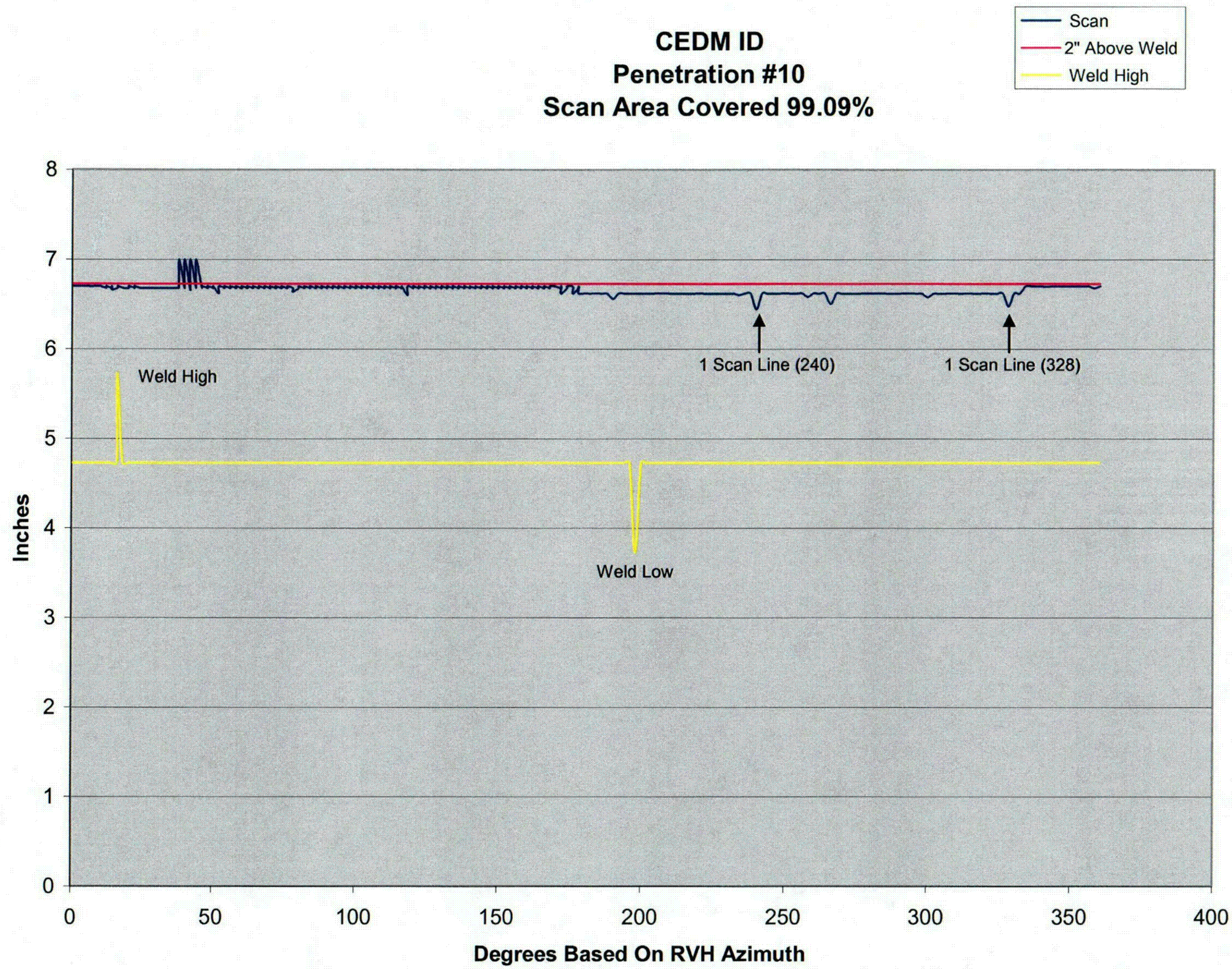
C09


Scan
2" Above Weld
Weld High
CEDM ID
Penetration #7
Scan Area Covered 98.62%
8
7
6
5
4
3
2
1
0
Inches
1 Scan Line(186)
Weld High
Weld Low
1 Scan Line(238)
0
50
100
150
200
250
300
350
400
Degrees Based on RVH Azimuth

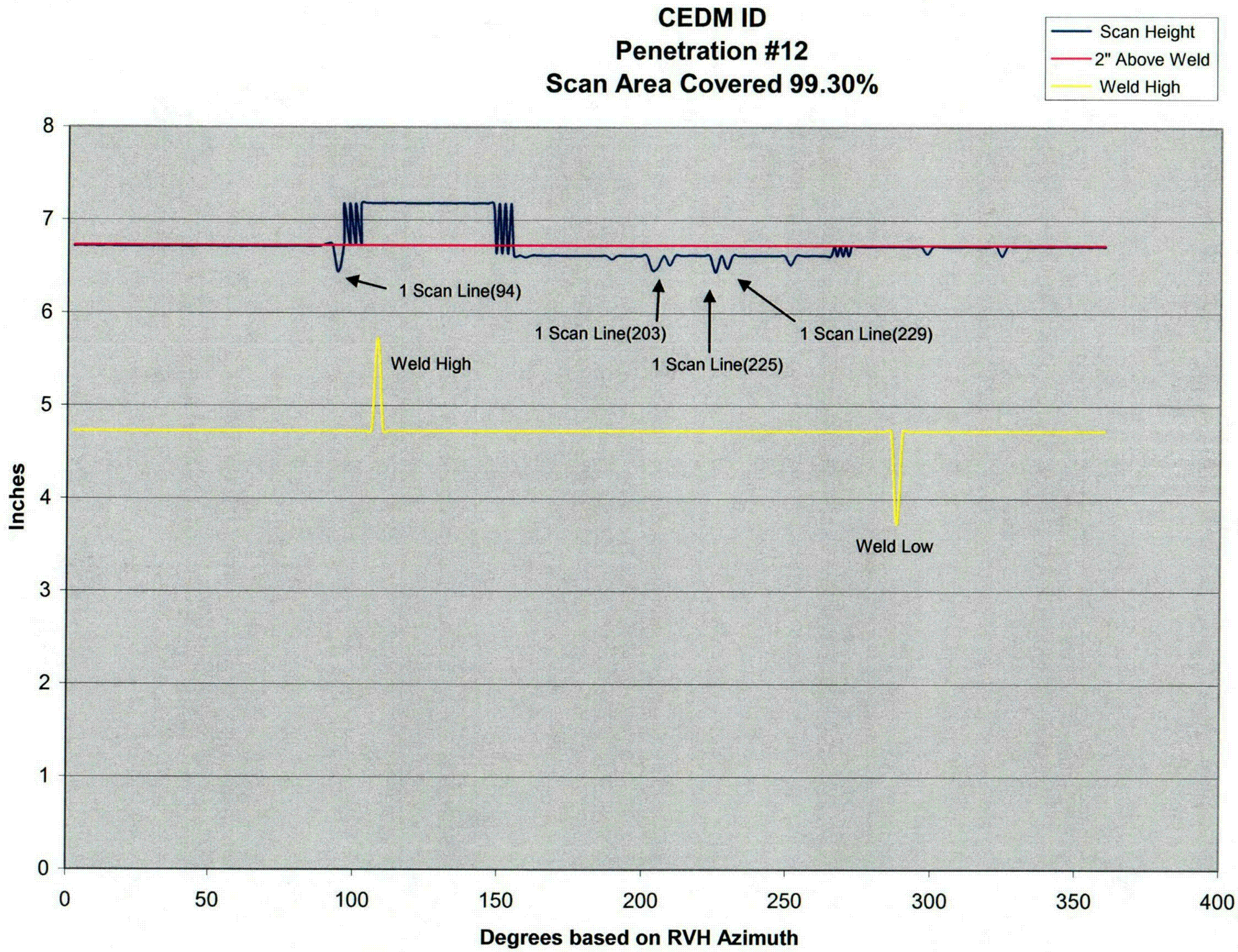
C10


CEDM ID
Penetration #8
Scan Area Covered 99.38%
8
7
6
5
4
3
2
1
0
Inches
0
50
100
150
200
250
300
350
400
Degrees based on RVH Azimuth
Weld High
Weld
Scan Height
Weld High
2" Above Weld

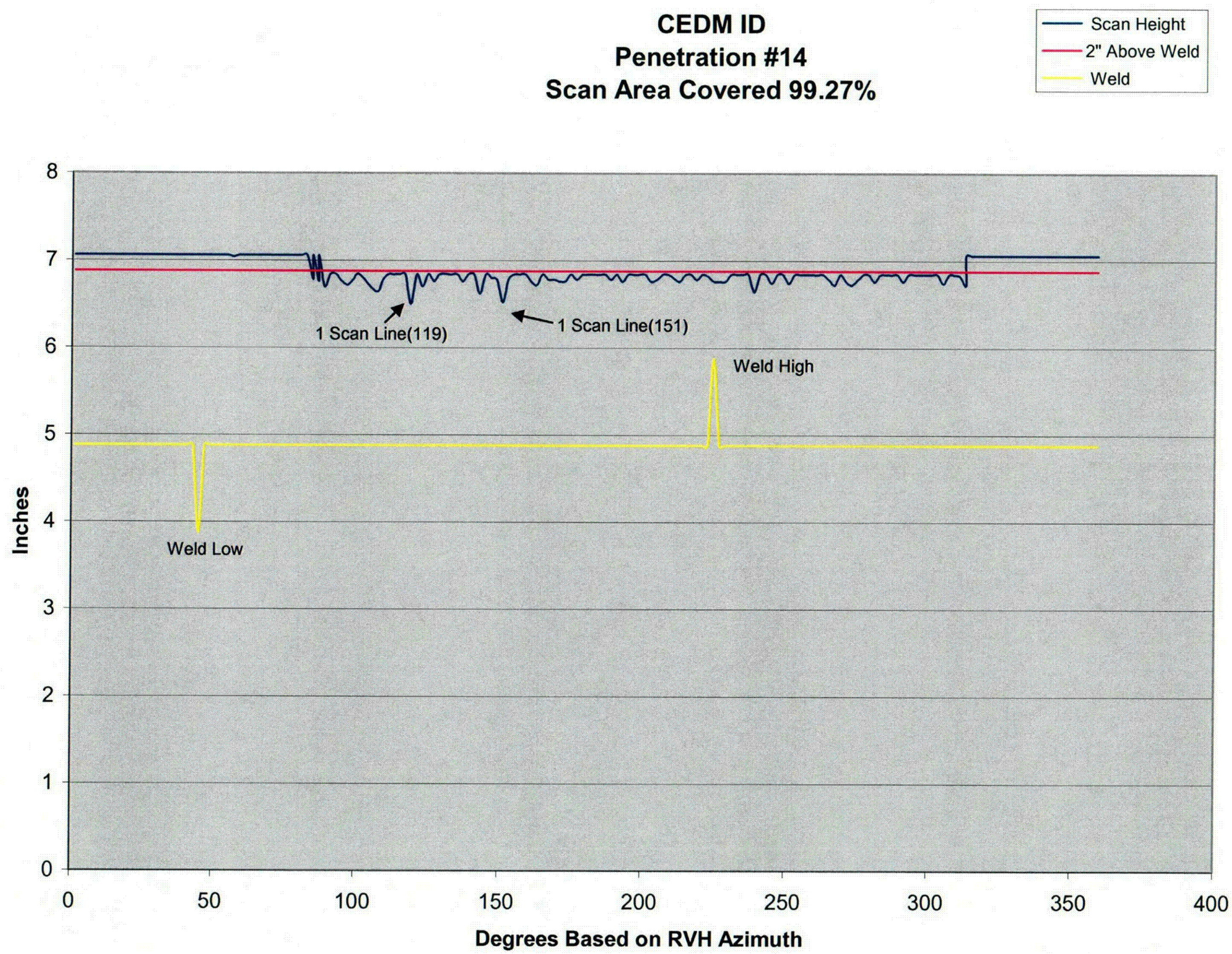
C11


CEDM ID
Penetration #10
Scan Area Covered 99.09%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
1 Scan Line (240)
1 Scan Line (328)
Inches
Degrees Based On RVH Azimuth
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400

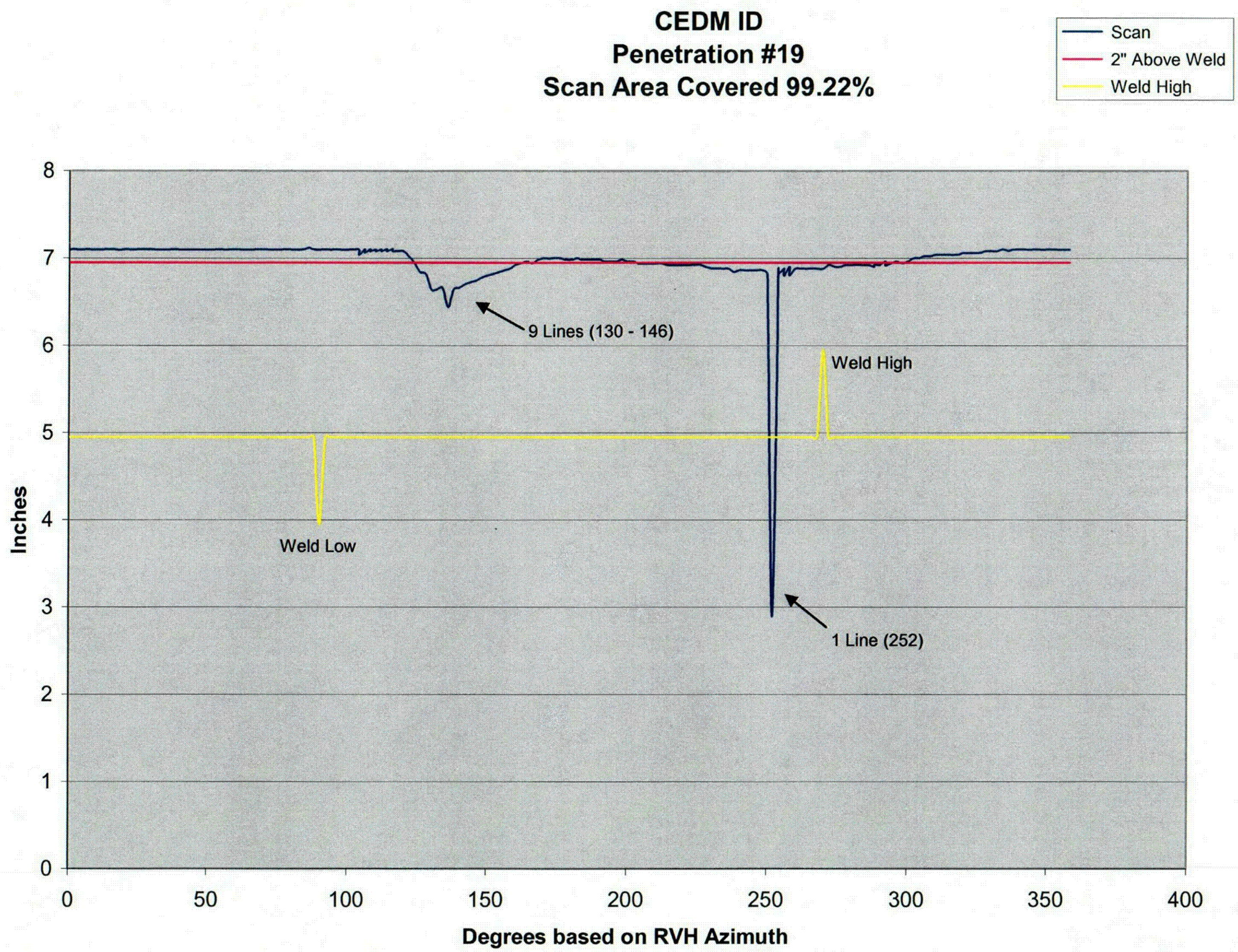
C12


CEDM ID
Penetration #12
Scan Area Covered 99.30%
Scan Height
2" Above Weld
Weld High
8
7
6
5
4
3
2
1
0
Inches
0
50
100
150
200
250
300
350
400
Degrees based on RVH Azimuth
1 Scan Line(94)
1 Scan Line(203)
1 Scan Line(229)
1 Scan Line(225)
Weld High
Weld Low

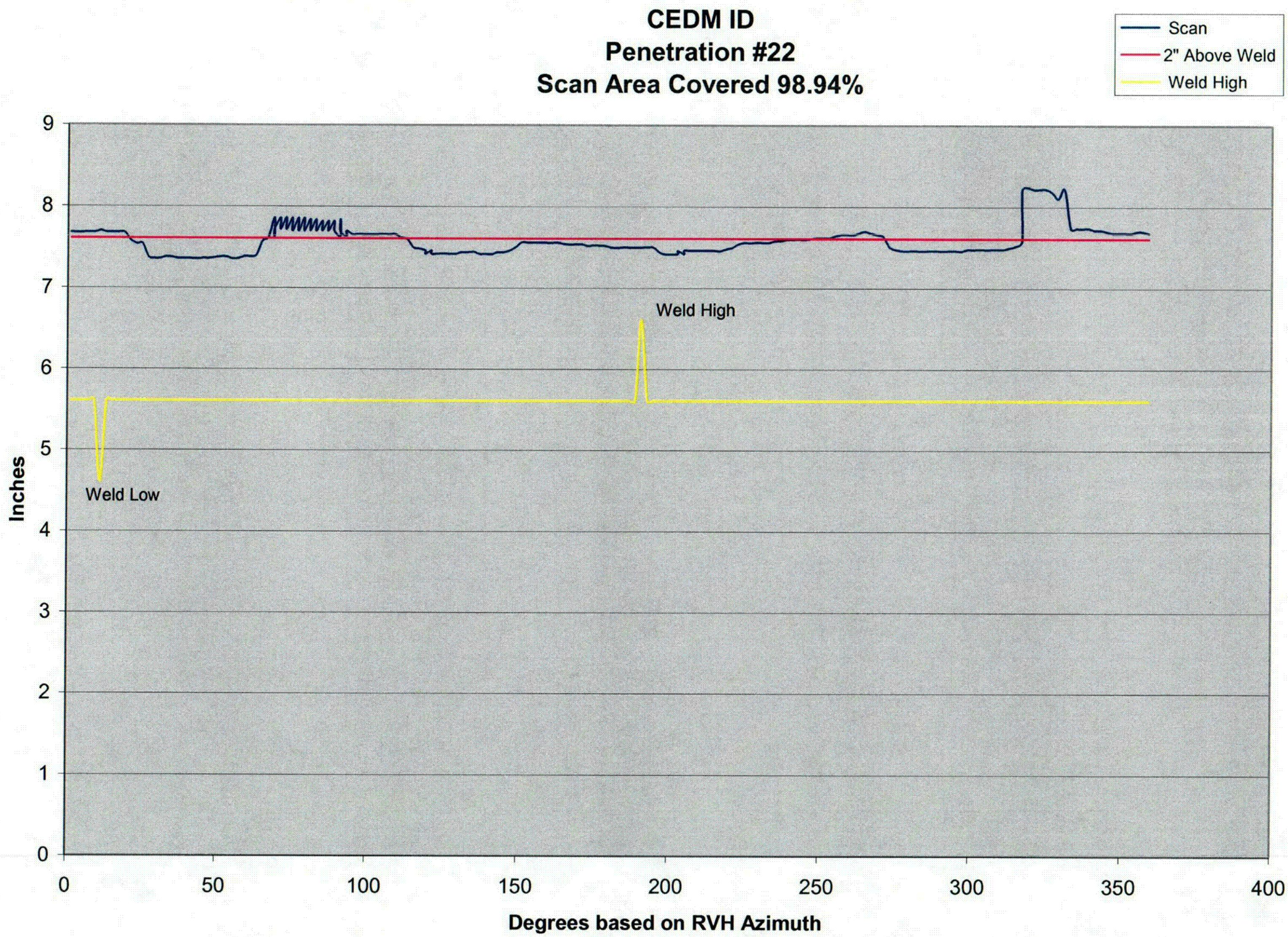
C13


CEDM ID
Penetration #14
Scan Area Covered 99.27%
Scan Height
2" Above Weld
Weld
8
7
6
5
4
3
2
1
0
Inches
1 Scan Line(119)
1 Scan Line(151)
Weld High
Weld Low
0
50
100
150
200
250
300
350
400
Degrees Based on RVH Azimuth

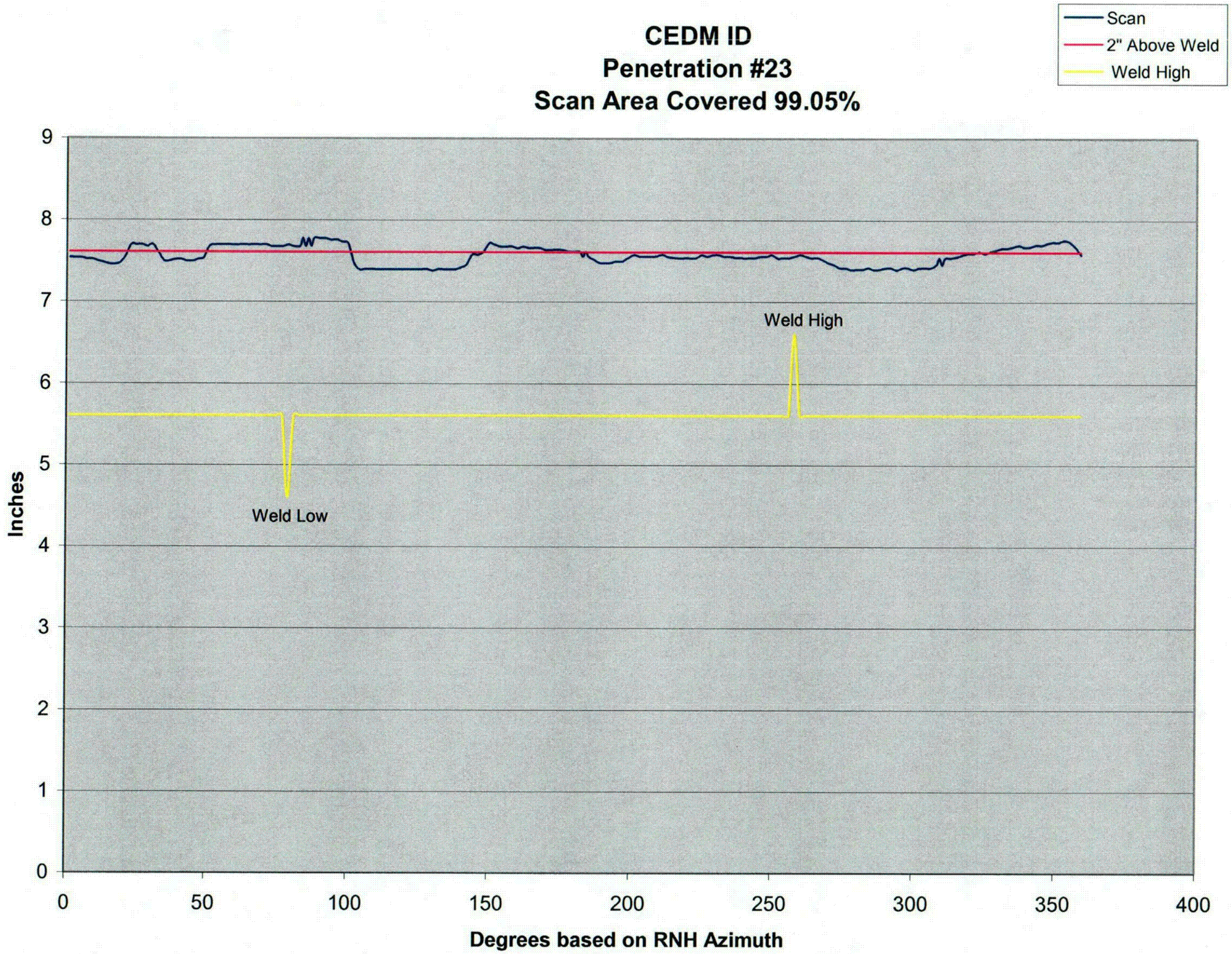
C14


CEDM ID
Penetration #19
Scan Area Covered 99.22%
Scan
2" Above Weld
Weld High
9 Lines (130 - 146)
Weld High
Weld Low
1 Line (252)
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400

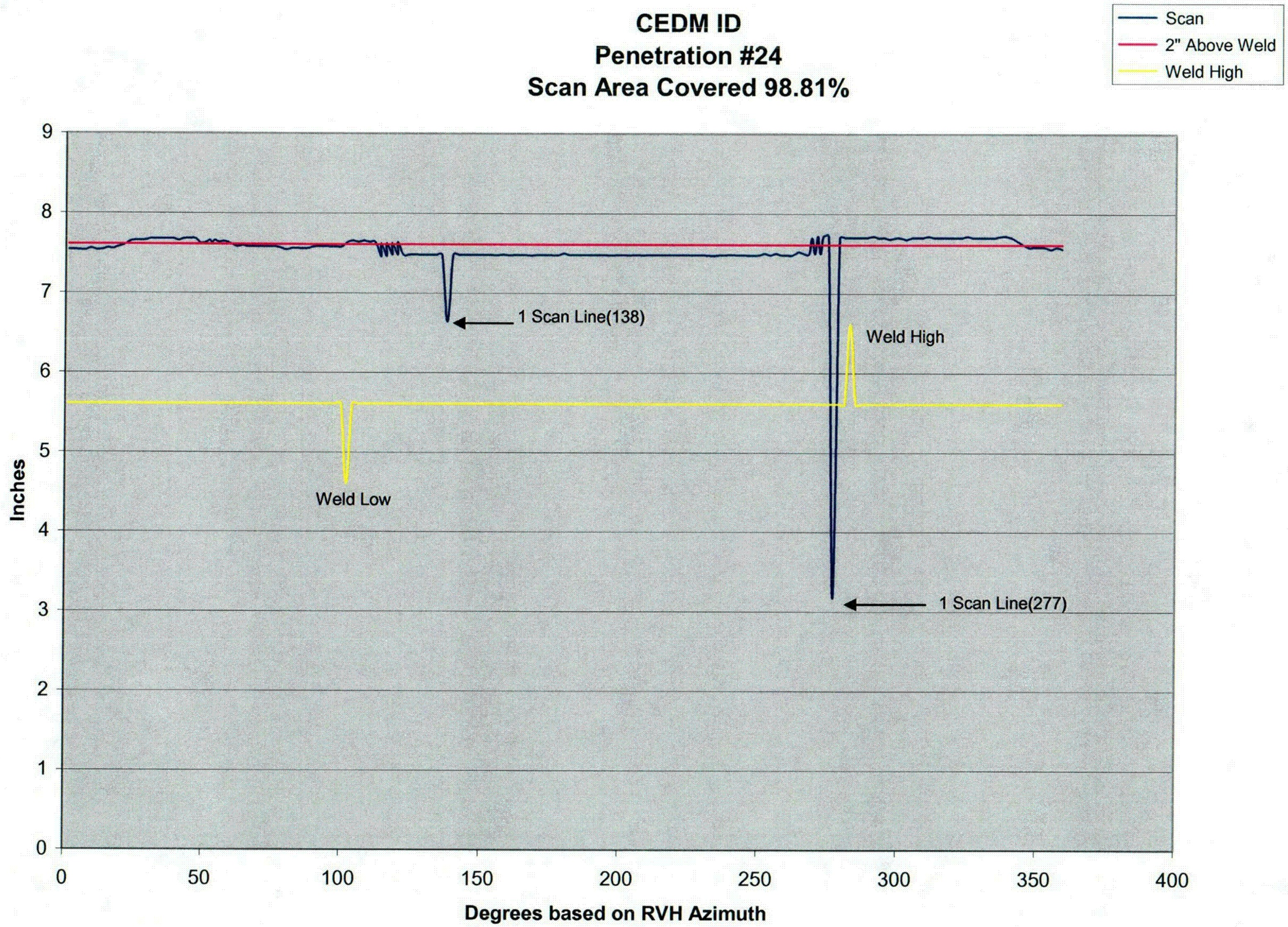
C15


CEDM ID
Penetration #22
Scan Area Covered 98.94%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

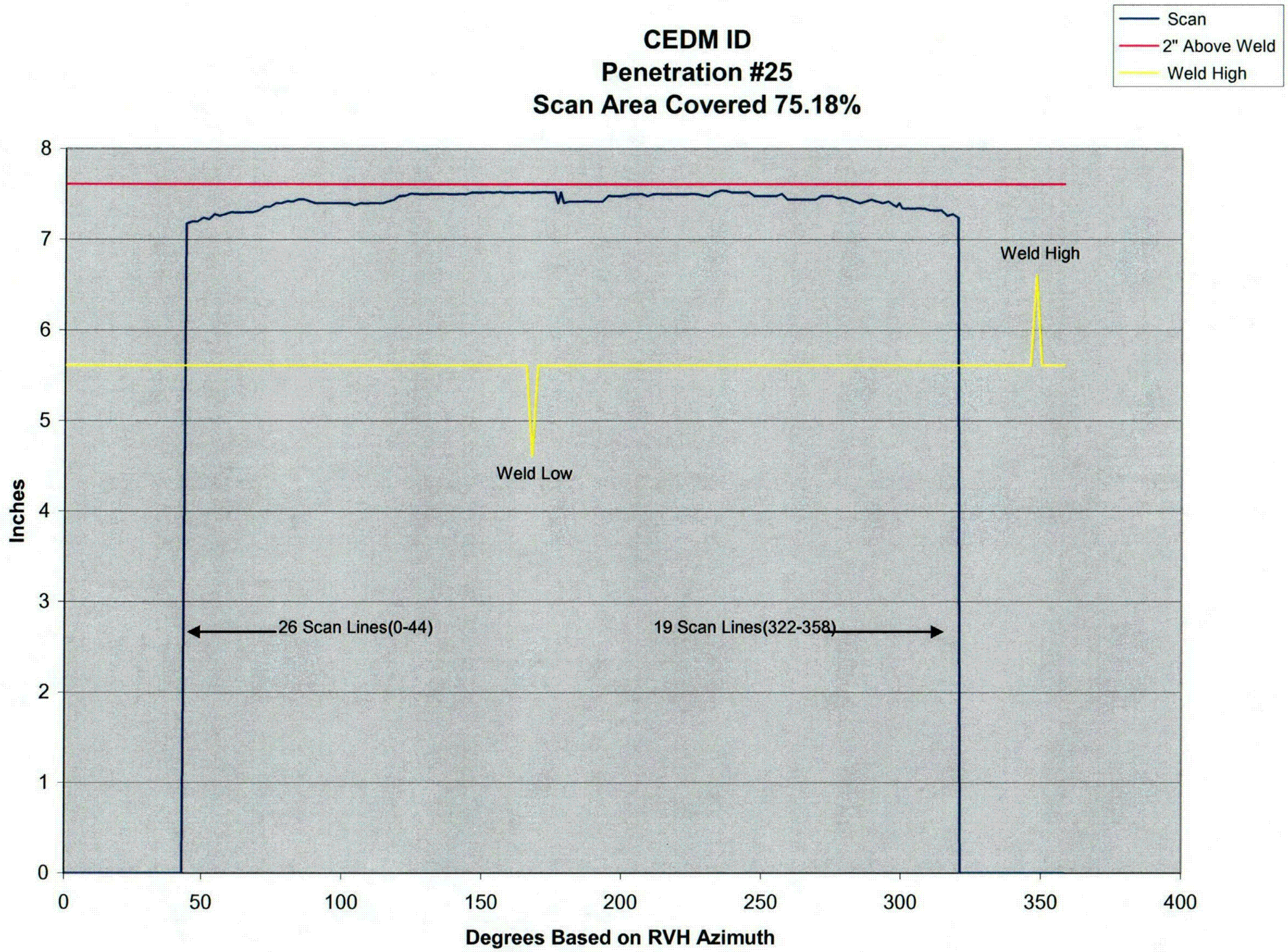
C16


CEDM ID
Penetration #23
Scan Area Covered 99.05%
Scan
2" Above Weld
Weld High
9
8
7
6
5
4
3
2
1
0
Inches
Weld High
Weld Low
0
50
100
150
200
250
300
350
400
Degrees based on RNH Azimuth

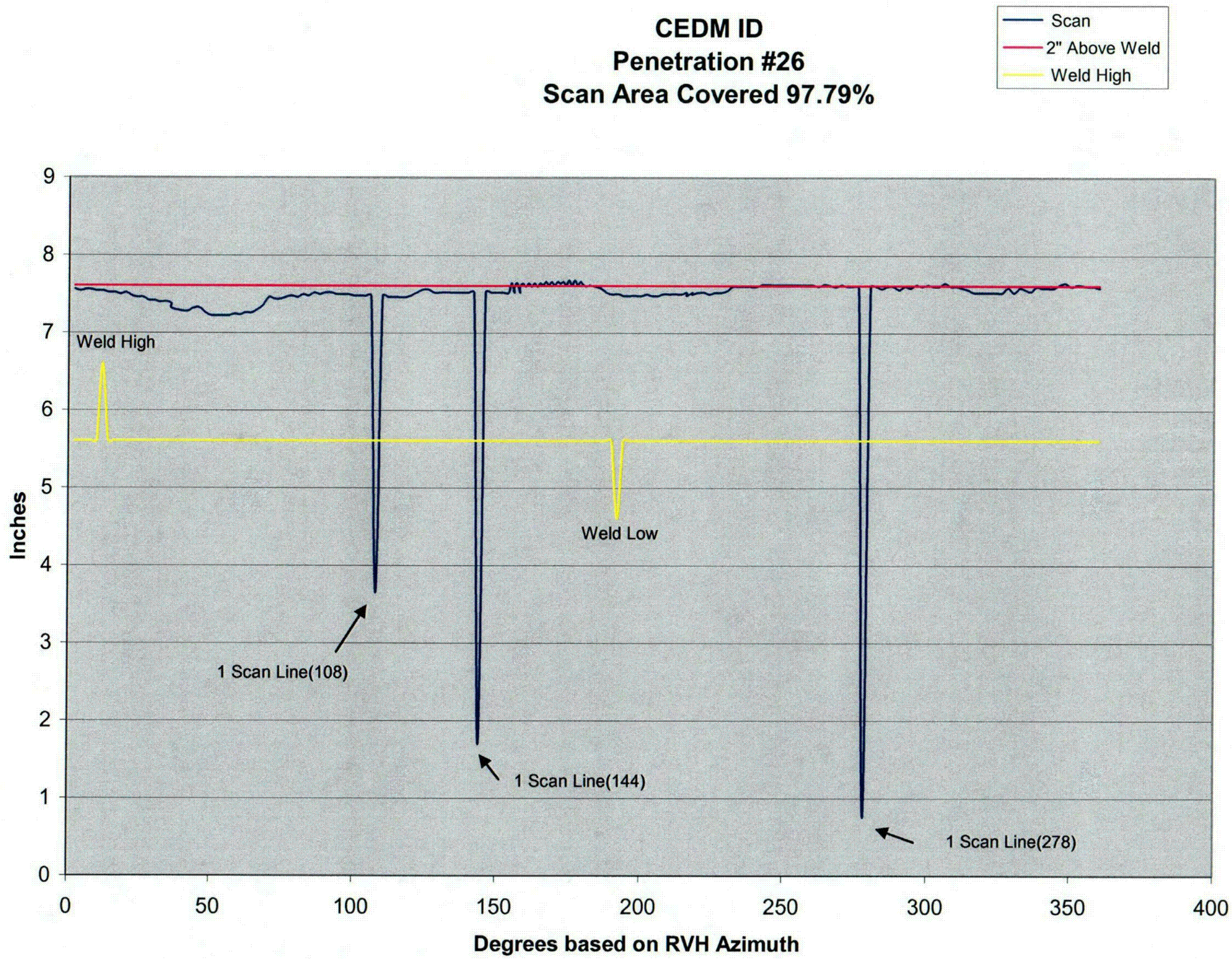
C17


CEDM ID
Penetration #24
Scan Area Covered 98.81%
Scan
2" Above Weld
Weld High
1 Scan Line(138)
Weld High
Weld Low
1 Scan Line(277)
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

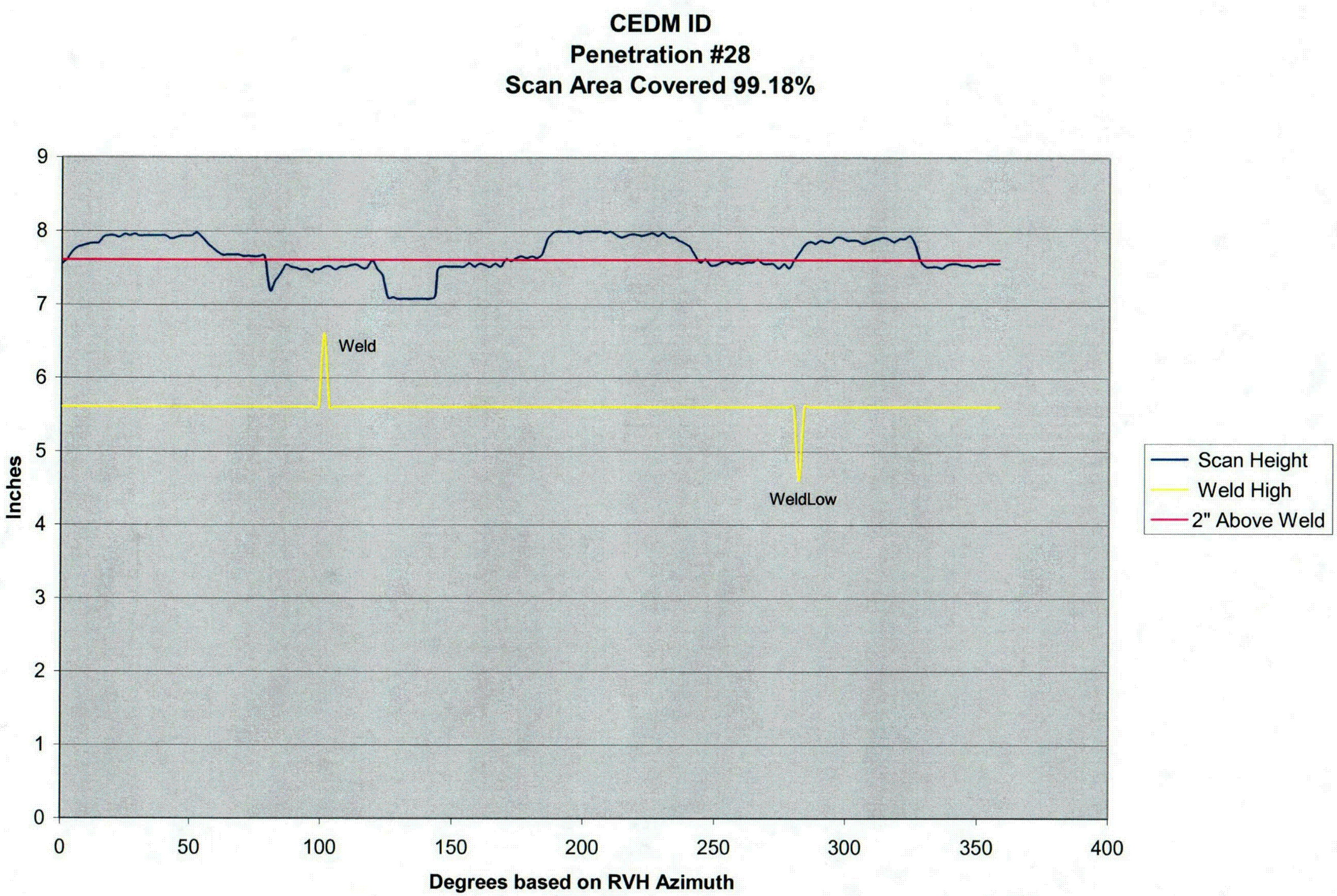
C18


CEDM ID
Penetration #25
Scan Area Covered 75.18%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
26 Scan Lines(0-44)
19 Scan Lines(322-358)
Inches
Degrees Based on RVH Azimuth
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400

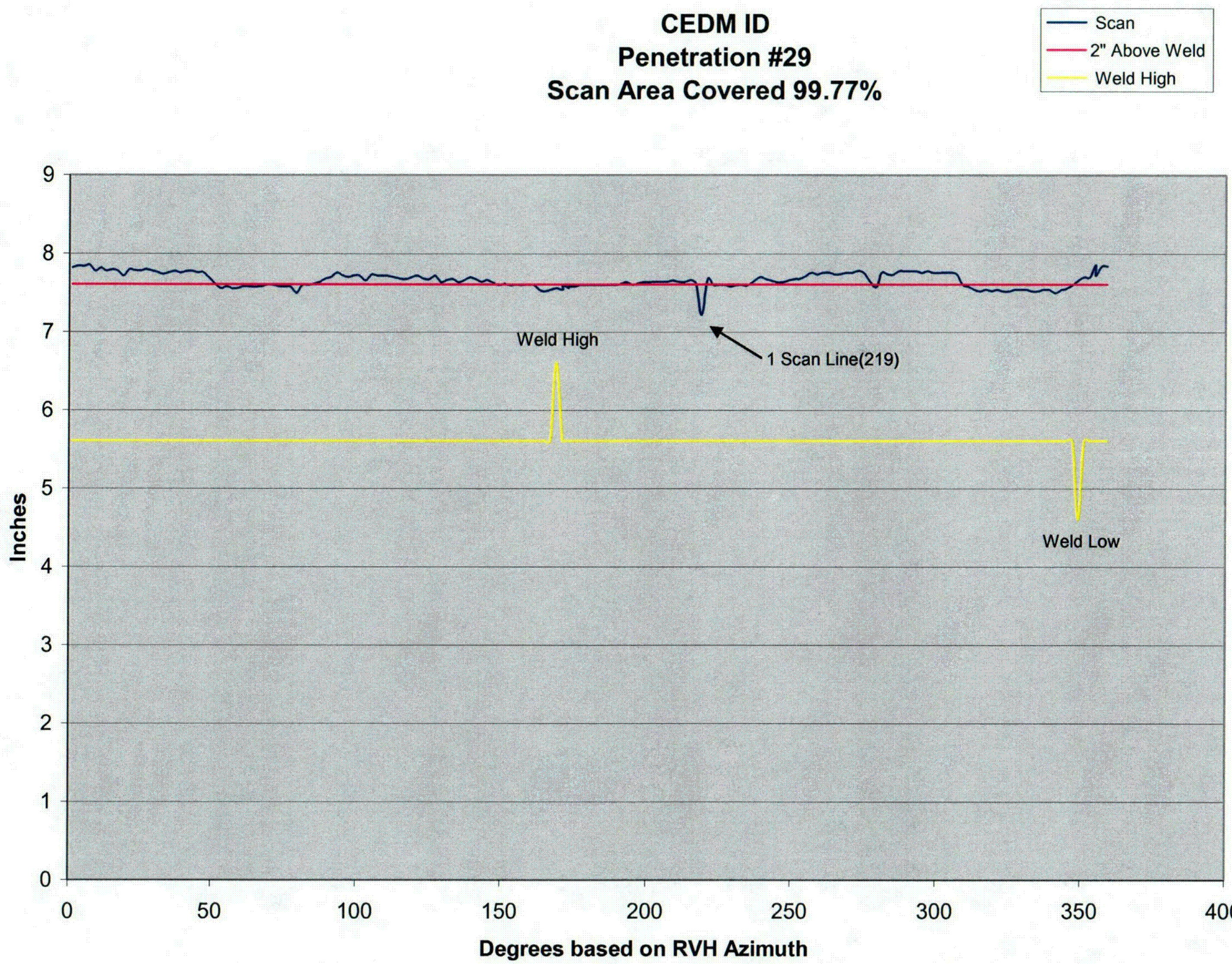
C19


CEDM ID
Penetration #26
Scan Area Covered 97.79%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
1 Scan Line(108)
1 Scan Line(144)
1 Scan Line(278)
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

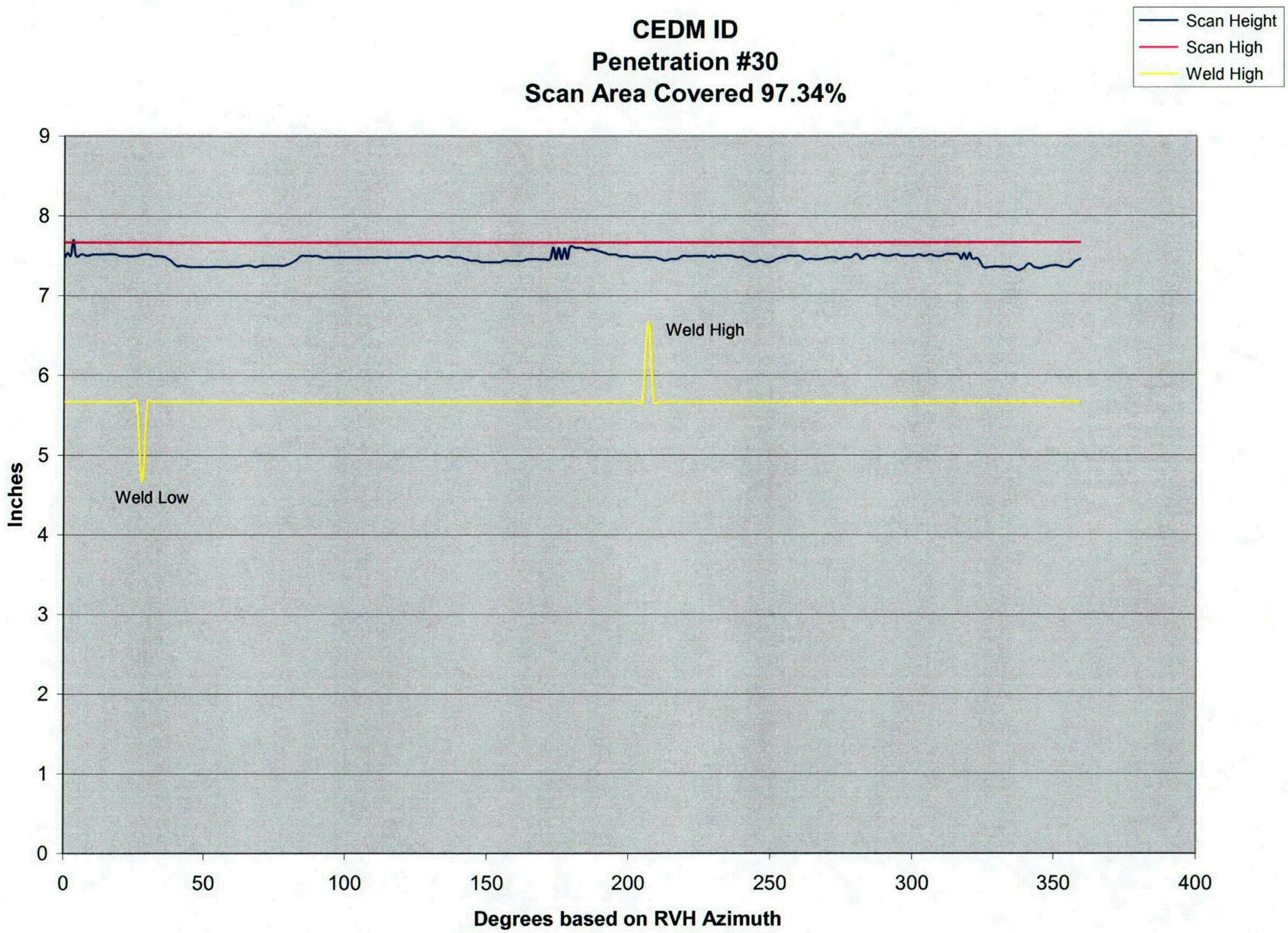
C20


CEDM ID
Penetration #28
Scan Area Covered 99.18%
9
8
7
6
5
4
3
2
1
0
Inches
0
50
100
150
200
250
300
350
400
Degrees based on RVH Azimuth
Weld
WeldLow
Scan Height
Weld High
2" Above Weld

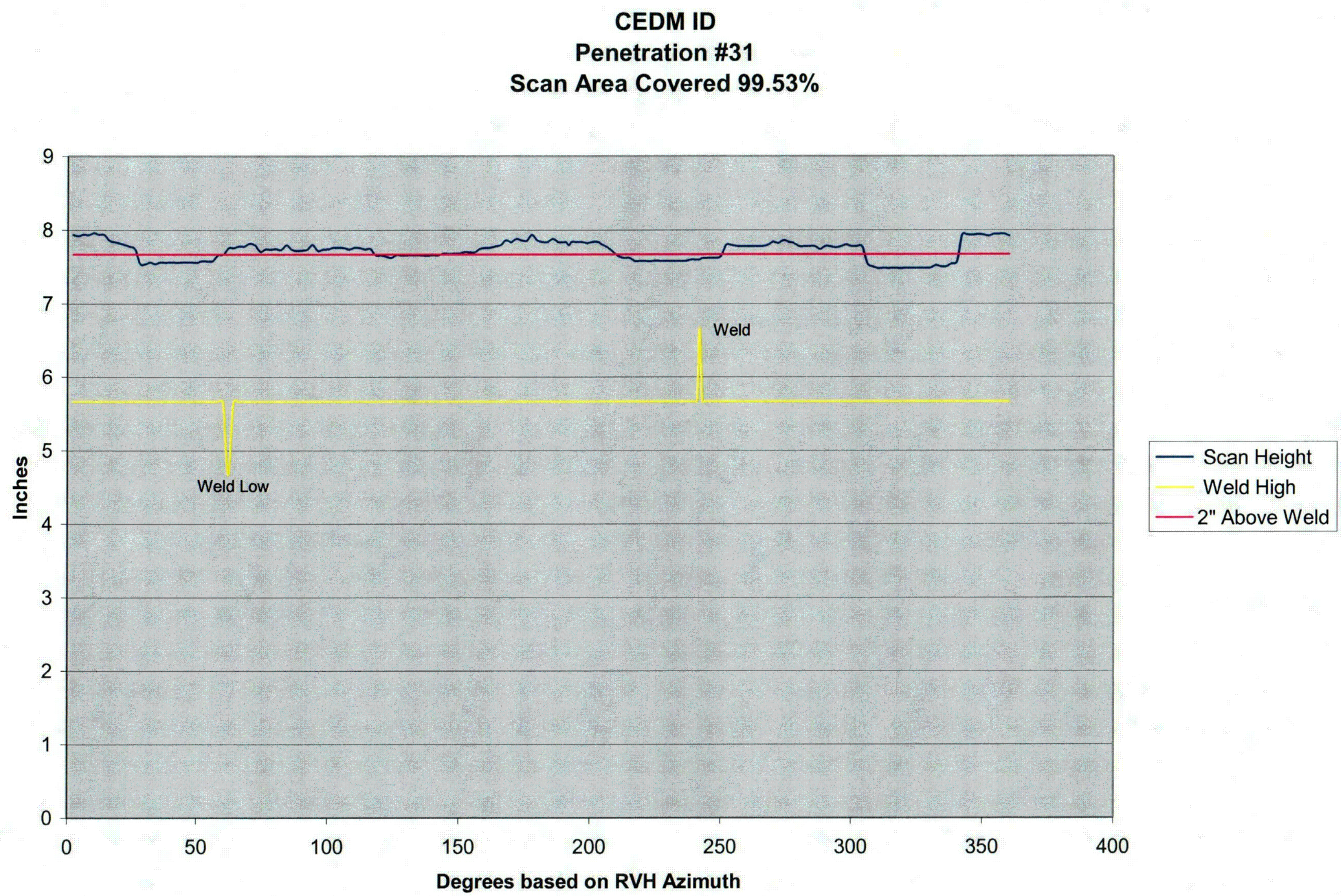
C21


CEDM ID
Penetration #29
Scan Area Covered 99.77%
Scan
2" Above Weld
Weld High
Weld High
1 Scan Line(219)
Weld Low
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

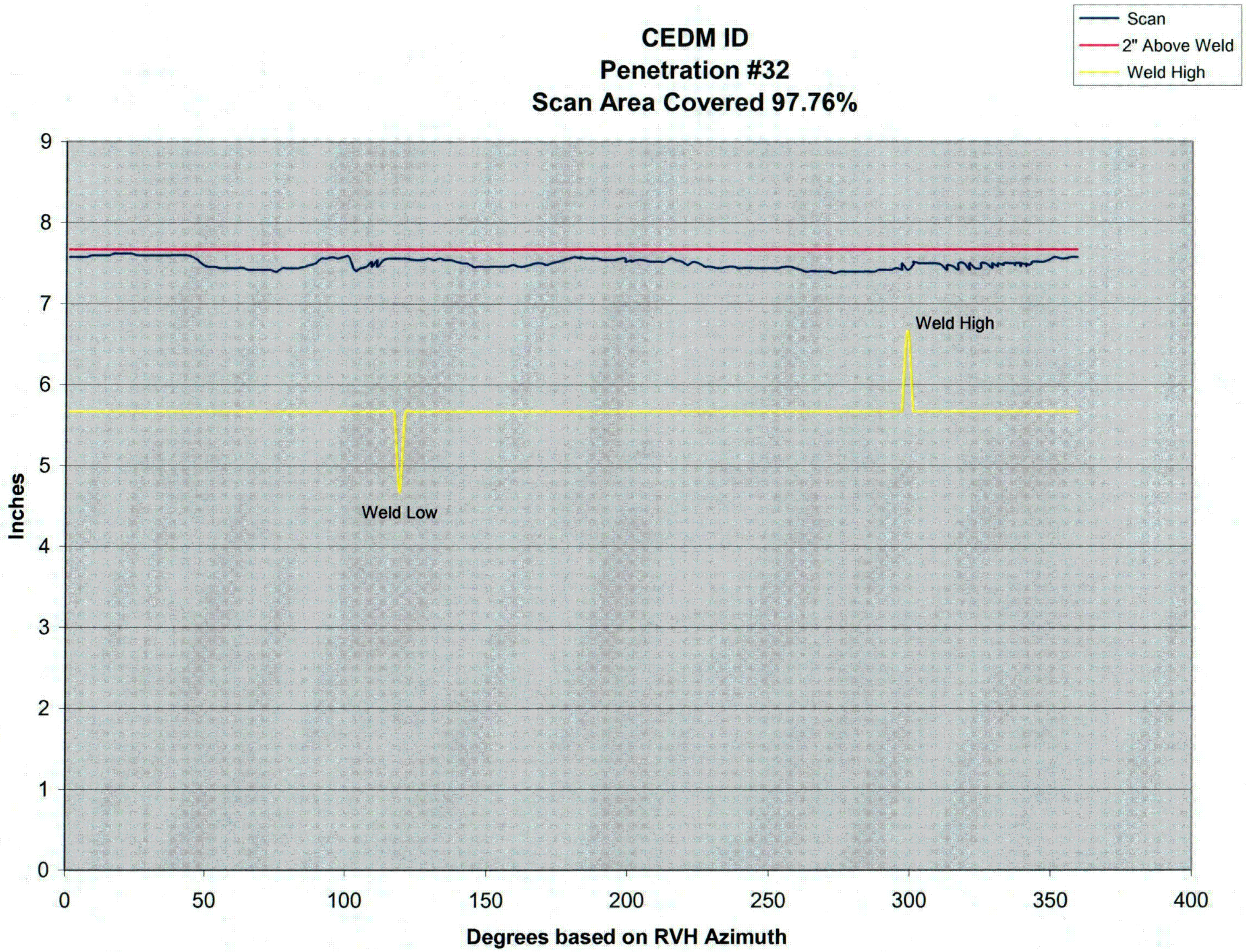
CZZ


CEDM ID
Penetration #30
Scan Area Covered 97.34%
Scan Height
Scan High
Weld High
Weld High
Weld Low
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

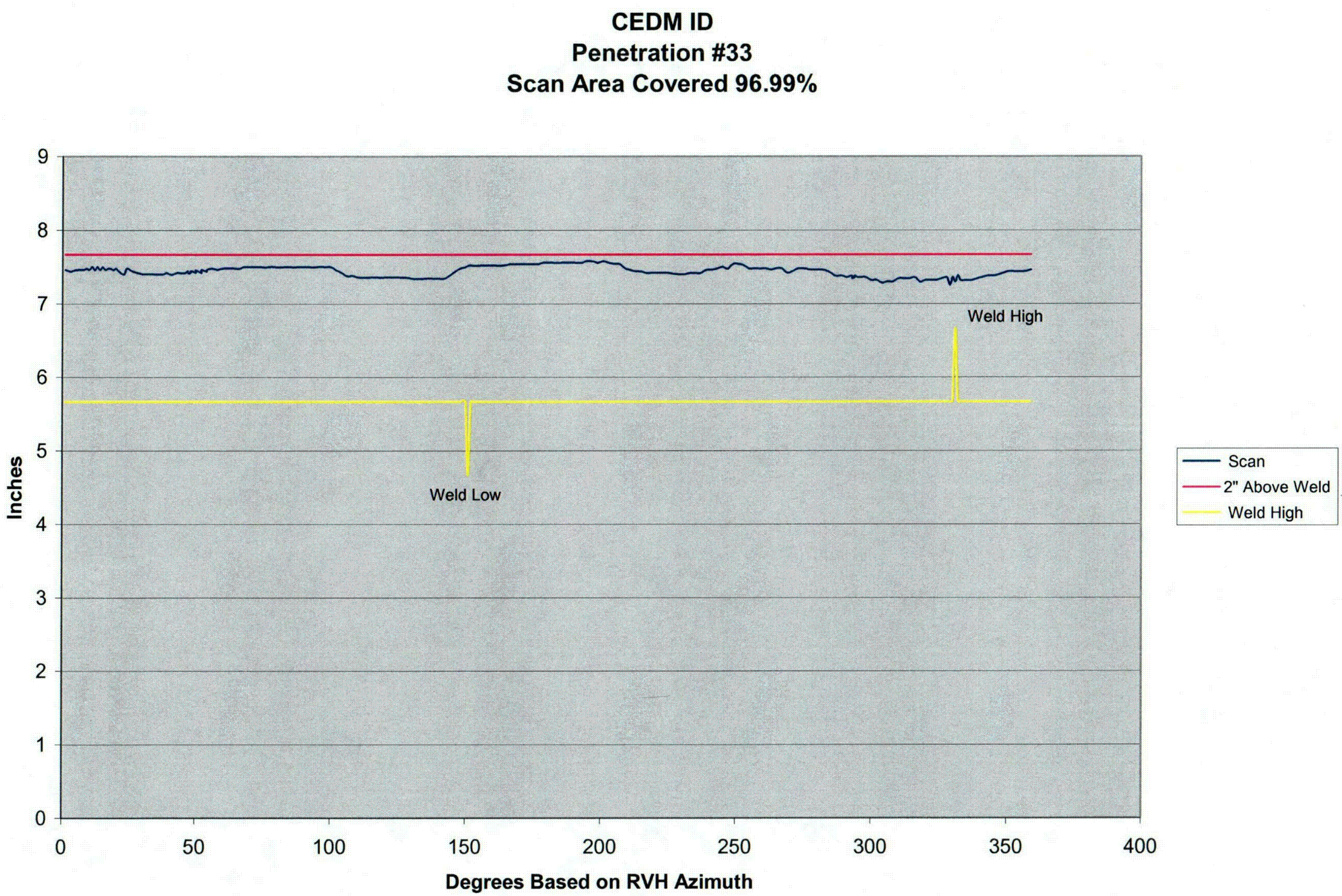
C23


CEDM ID
Penetration #31
Scan Area Covered 99.53%
9
8
7
6
5
4
3
2
1
0
Inches
Weld
Weld Low
0
50
100
150
200
250
300
350
400
Degrees based on RVH Azimuth
Scan Height
Weld High
2" Above Weld

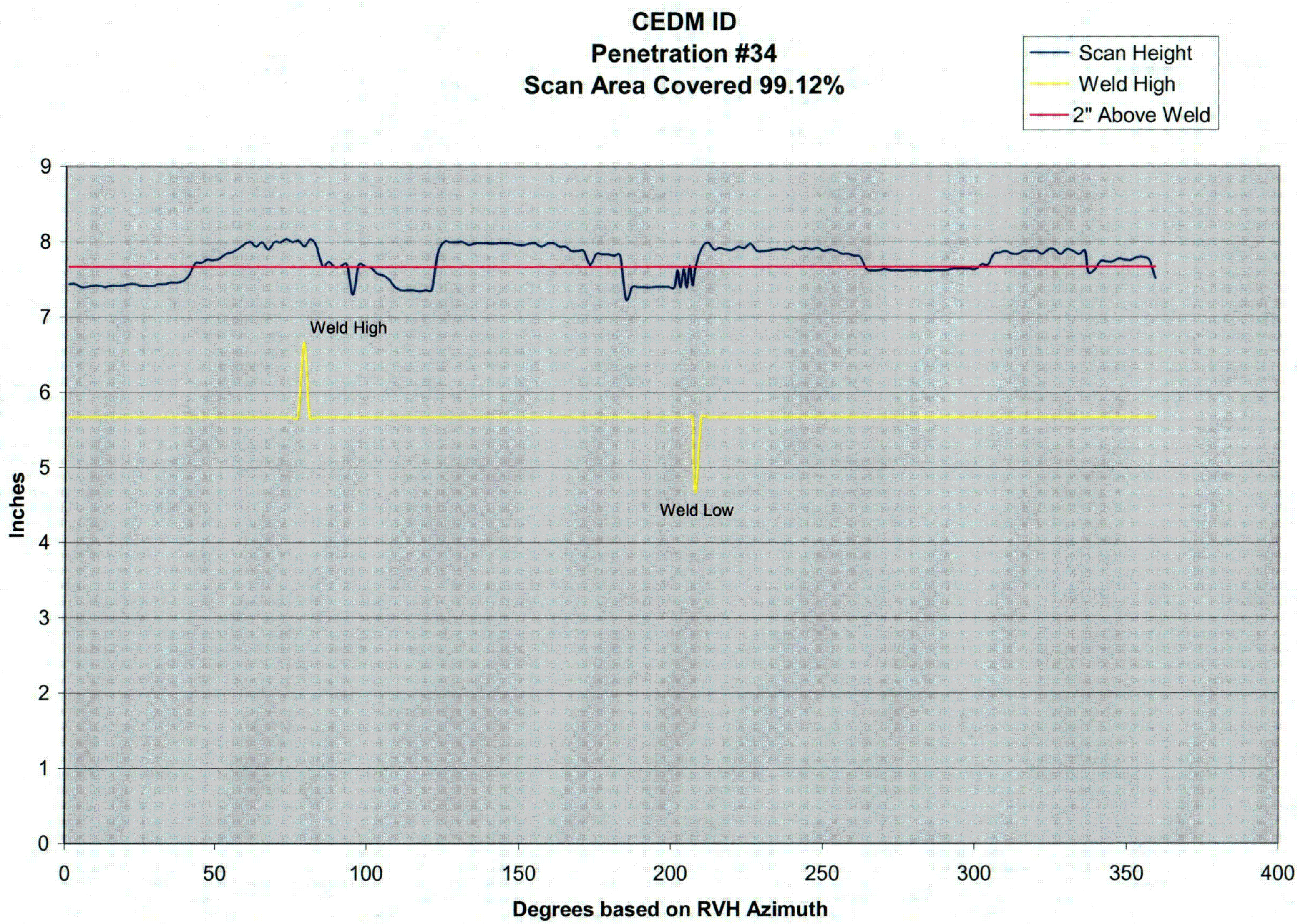
C24


CEDM ID
Penetration #32
Scan Area Covered 97.76%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

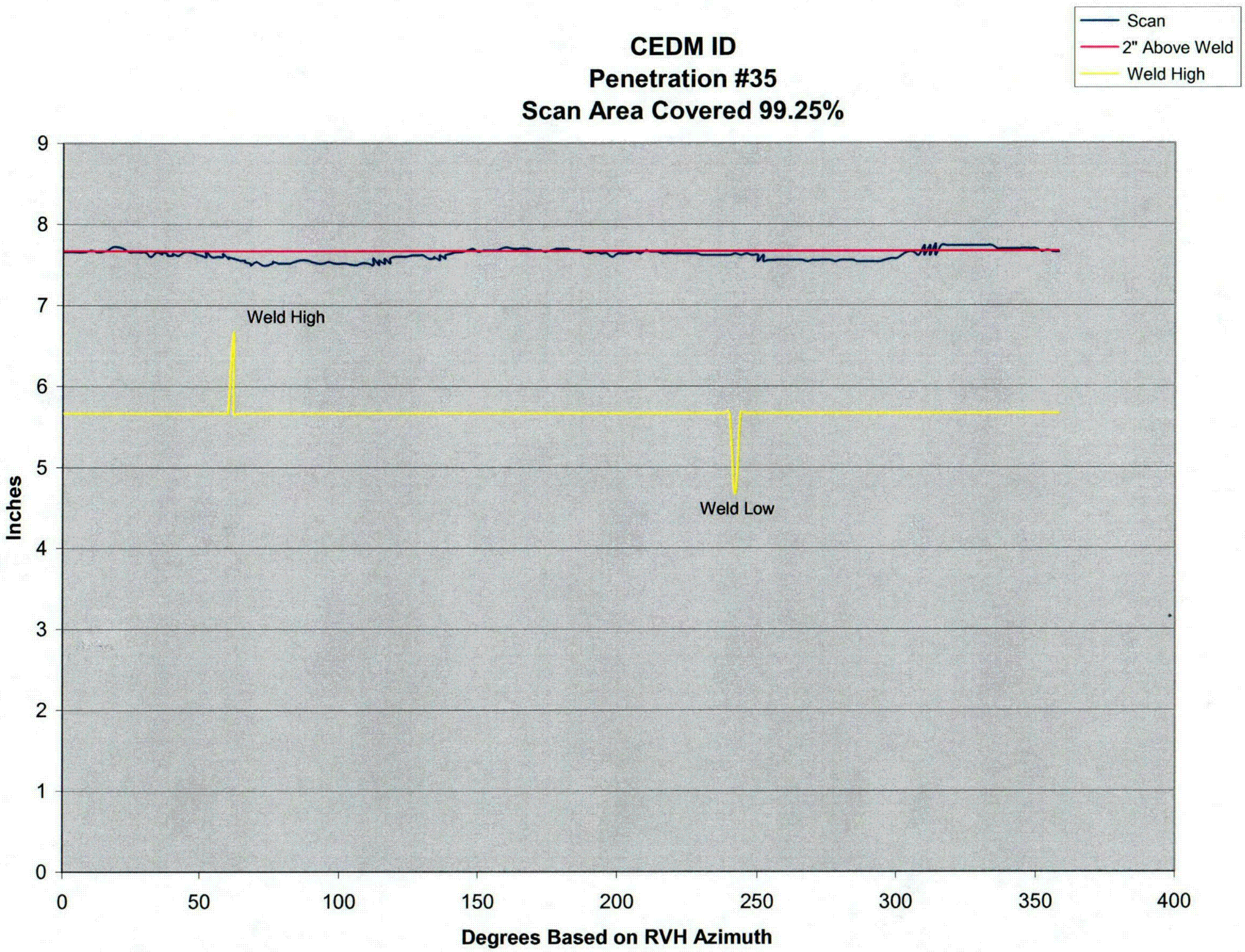
C25


CEDM ID
Penetration #33
Scan Area Covered 96.99%
Inches
9
8
7
6
5
4
3
2
1
0
0
50
100
150
200
250
300
350
400
Degrees Based on RVH Azimuth
Weld High
Weld Low
Scan
2" Above Weld
Weld High

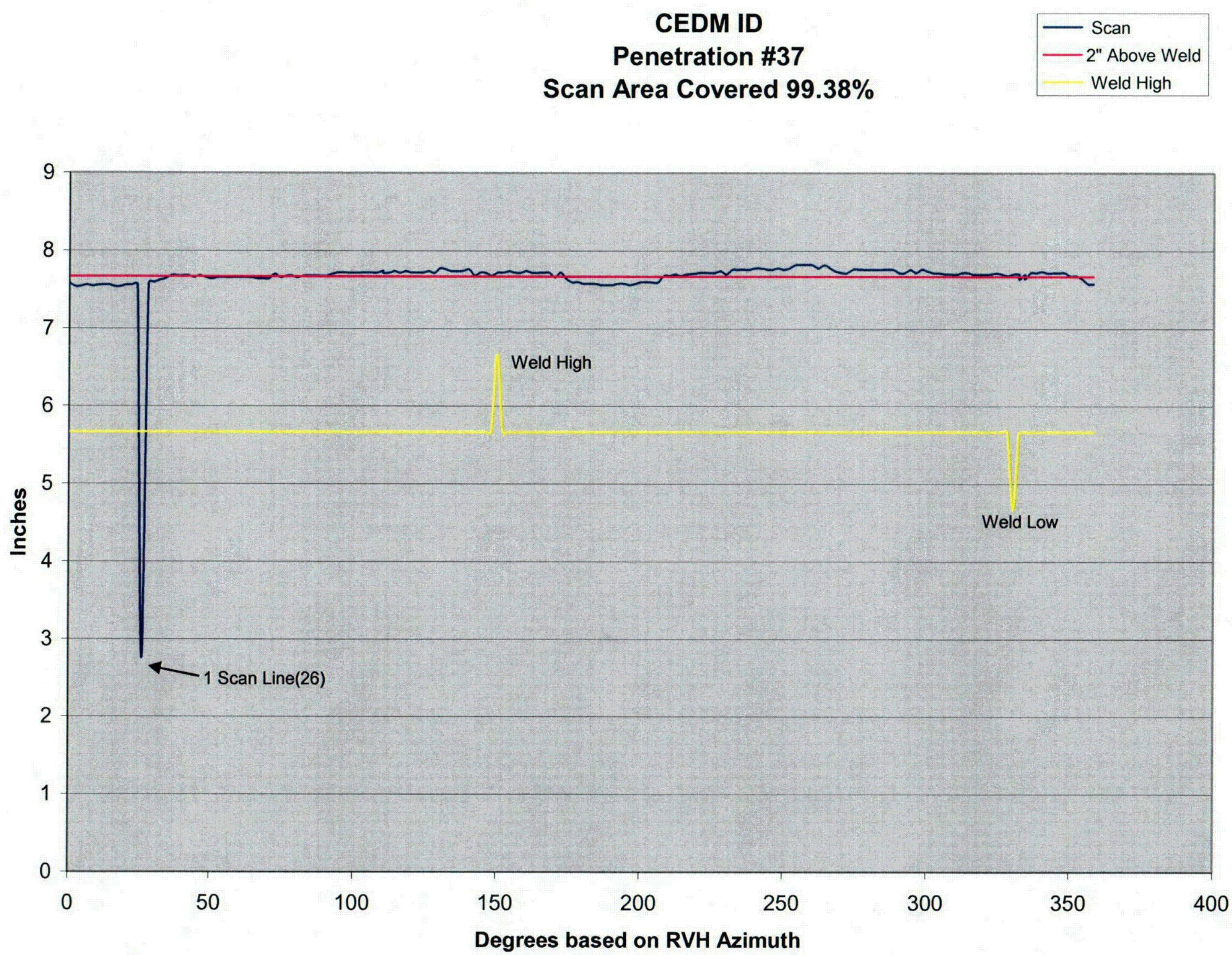
C26


CEDM ID
Penetration #34
Scan Area Covered 99.12%
Scan Height
Weld High
2" Above Weld
9
8
7
6
5
4
3
2
1
0
Inches
Weld High
Weld Low
0
50
100
150
200
250
300
350
400
Degrees based on RVH Azimuth

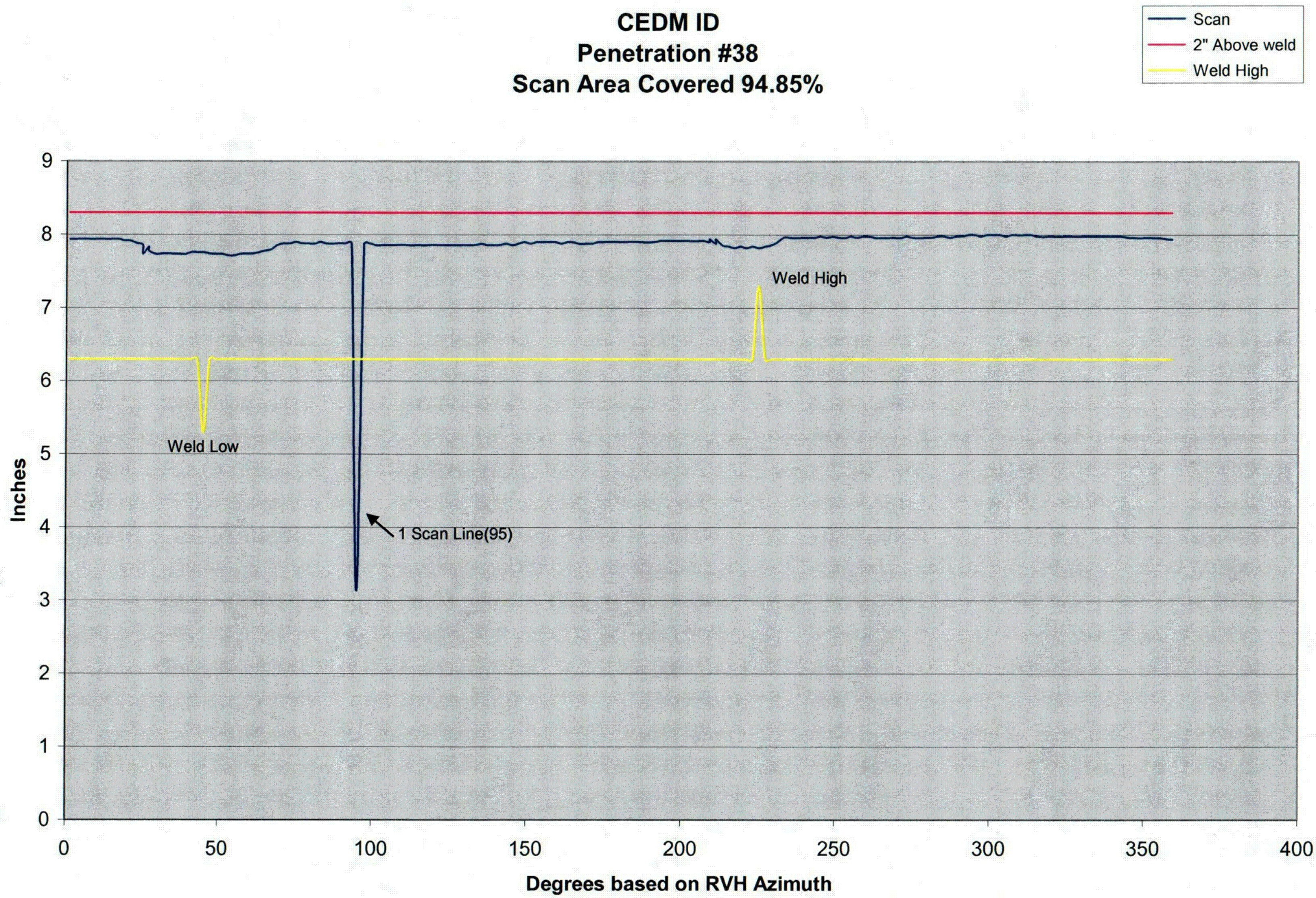
C27


CEDM ID
Penetration #35
Scan Area Covered 99.25%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
Inches
Degrees Based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

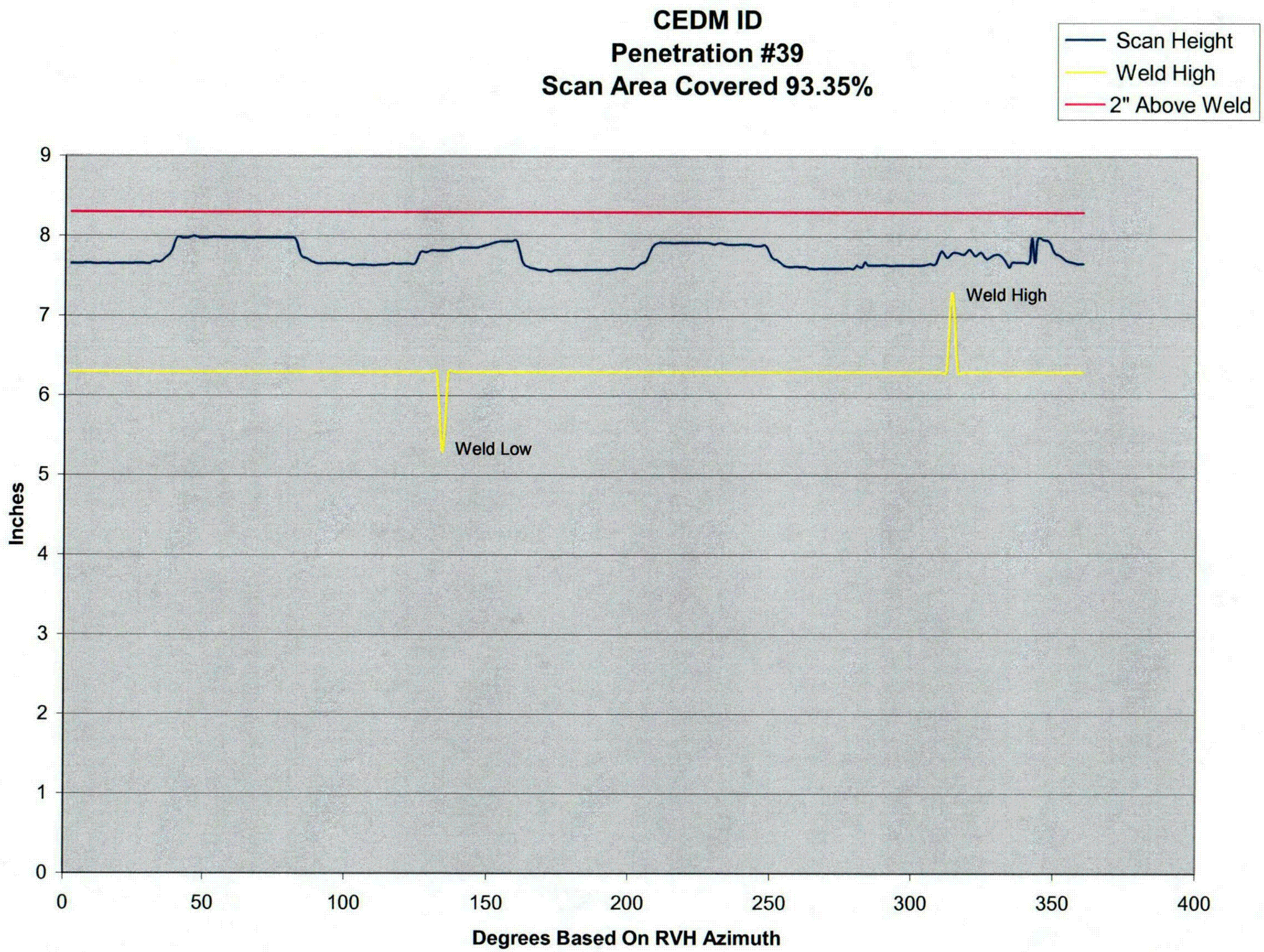
C28


CEDM ID
Penetration #37
Scan Area Covered 99.38%
Scan
2" Above Weld
Weld High
Inches
Degrees based on RVH Azimuth
Weld High
Weld Low
1 Scan Line(26)
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

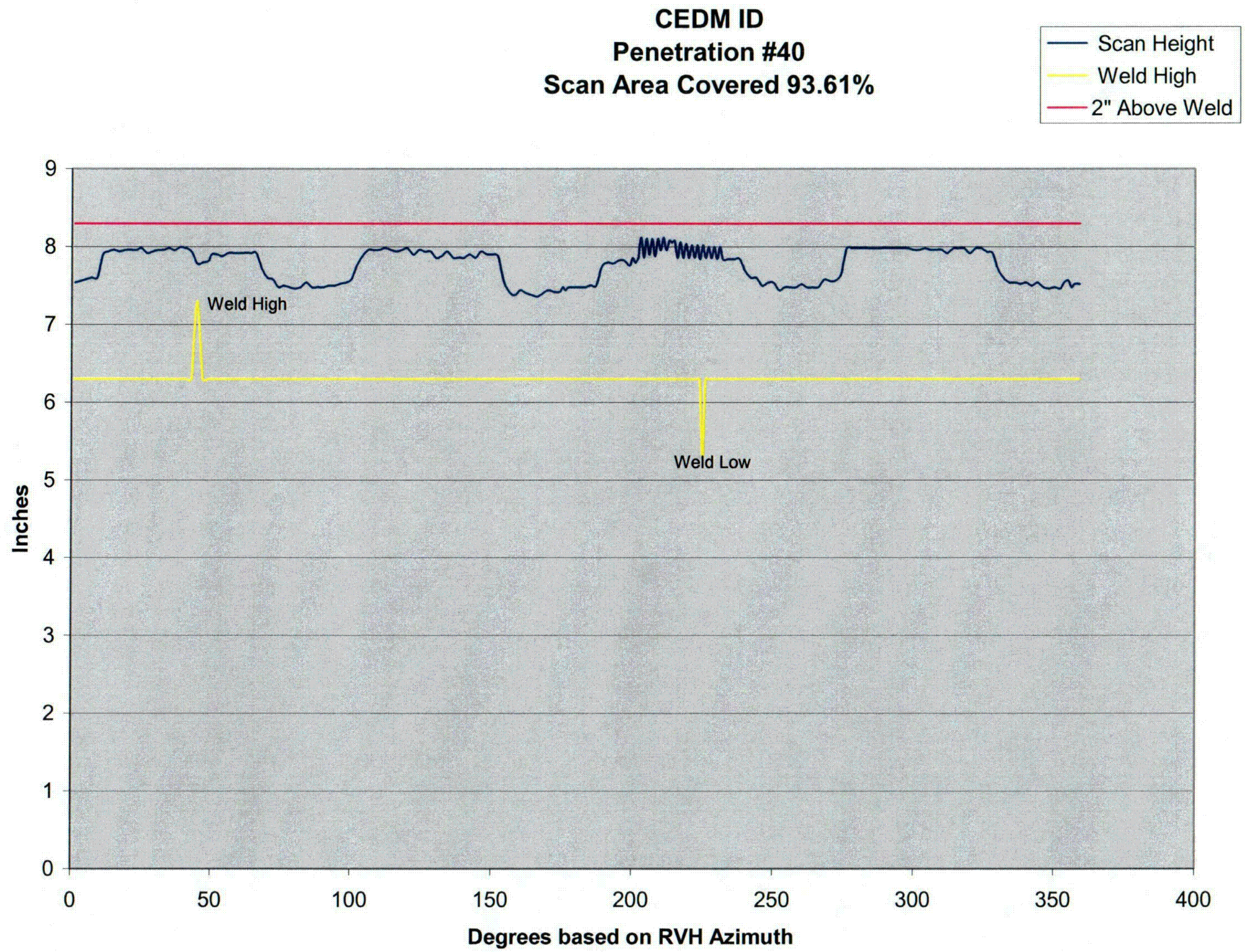
C29


CEDM ID
Penetration #38
Scan Area Covered 94.85%
Scan
2" Above weld
Weld High
9
8
7
6
5
4
3
2
1
0
Inches
Weld High
Weld Low
1 Scan Line(95)
0
50
100
150
200
250
300
350
400
Degrees based on RVH Azimuth

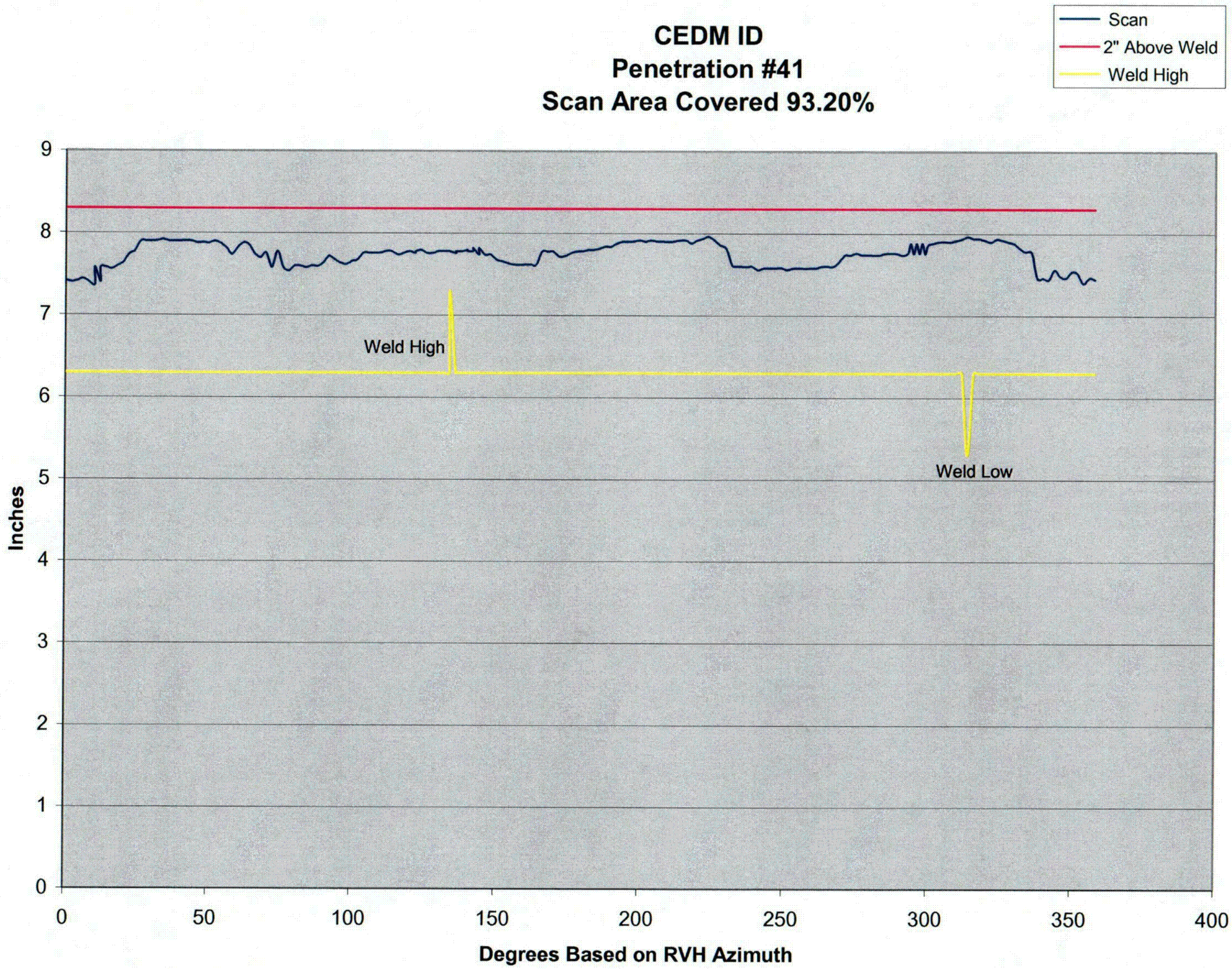
C30


CEDM ID
Penetration #39
Scan Area Covered 93.35%
Scan Height
Weld High
2" Above Weld
Weld High
Weld Low
Inches
Degrees Based On RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

C31


CEDM ID
Penetration #40
Scan Area Covered 93.61%
Scan Height
Weld High
2" Above Weld
Weld High
Weld Low
Inches
Degrees based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

C32


CEDM ID
Penetration #41
Scan Area Covered 93.20%
Scan
2" Above Weld
Weld High
Weld High
Weld Low
Inches
Degrees Based on RVH Azimuth
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
400

C33

Attachment 2

Westinghouse Letter CFTC-05-54, Report on Flaw Evaluation for Fort Calhoun Upper Head Penetrations, May 2005

Attachment 2

Westinghouse Letter CFTC-05-54, Report on Flaw Evaluation for Fort Calhoun Upper Head Penetrations, May 2005

Executive Summary

Section 1.0 – Introduction - This section provides an overview of the process used to assess the hoop stresses for the crack growth calculations for the areas in which relaxation is requested.

Section 2.0 – Hoop Stress Distribution Above the Root of the J-Groove Weld - A discussion of the hoop stresses found above all of the J-groove welds is provided and graphic results are provided in Figures 1 – 10.

Section 3.0 Hoop Stress Distribution Below the Toe of the J-Groove Weld - This section completes the hoop stress assessments by presenting the results in areas below the toe of all of the J-groove welds, as shown in Figures 11 – 19.

Section 4.0 - Flaw Evaluation for Lack of Inspection Coverage on the CEDM Uphill Side - Crack growth calculations for CEDM nozzle angles of 24.6°, 37.3° and 41.7° are presented with the basis of why these crack growths are conservative. Figure 20 graphically summarizes these calculations.

Section 5.0 Impact of Circumferential Flaws on Inspection Coverage Adequacy - This section provides the justification for that CEDM nozzle ejection is an unlikely scenario.

Section 6.0 References

1.0 Introduction

The objective of this analysis was to obtain accurate stresses in the Control Element Drive Mechanism (CEDM) and In-Core Instrumentation (ICI) penetration nozzle and its immediate vicinity. To do so requires a three dimensional finite element analysis [1] that considers all the pertinent loadings on the penetrations. Four CEDM locations with nozzle angles of 0°, 24.6°, 37.3°, 41.7° and one ICI nozzle with nozzle angle of 54.4° were analyzed. The analyses were used to provide information for the flaw tolerance evaluation and/or determine adequacy of the inspection coverage.

A three-dimensional finite element model comprised of isoparametric brick and wedge elements was used to obtain the stresses and deflections. Taking advantage of the symmetry of the vessel head, only half of a CEDM/ICI penetration nozzle was modeled. In the model, the lower portion of the CEDM/ICI penetration nozzle, the adjacent section of the vessel closure head, and the joining weld were modeled. The vessel to penetration nozzle weld was simulated with two weld passes. The penetration nozzle, weld metal, cladding and the vessel head shell were modeled in accordance with the relevant material properties.

The most important loading conditions were found to be those which exist on the penetration for the majority of the time. These loadings included internal pressure and thermal expansion effects typical of steady state operation. The reactor vessel head temperature for Fort Calhoun used in the analysis is 588°F. In addition, residual stresses due to the welding of the penetrations to the vessel head were considered.

The hoop stress in the penetration nozzle resulting from the steady state operation loadings and welding residual stresses is much higher than the axial stress [1]. This is consistent with the field findings, where the cracks discovered are generally oriented axially. Typically, in-service cracks will orient themselves perpendicular to the largest stress component. Also it should be noted that the highest tensile hoop stress is at the uphill side and downhill side locations rather than midway around the penetration, where it is less limiting. This is consistent with finding axial cracks only in the vicinity of the uphill side and downhill side locations. It is these steady state hoop stresses that will be used to predict crack propagation in the penetration nozzles.

The associated hoop stress distributions on the downhill and uphill side along the length of the penetration nozzles above and below the J-groove weld are presented in Section 2.0 and 3.0. In addition, flaw tolerance charts are also generated to determine the predicted Primary Water Stress Corrosion Cracking (PWSCC) crack growth taking into account of various extent of inspection coverage achievable for the CEDM/ICI penetration nozzles.

2.0 Hoop Stress Distribution Above the Root of the J-Groove Weld

Figures 1-9 shows the hoop stress distributions for the regions that are within 2 inches from the top of the root of the J-groove weld on the uphill side for the Fort Calhoun reactor vessel upper head penetrations. The stress distributions shown are for the inside and outside surface of the reactor vessel upper head penetrations. The stress distributions shown in Figures 1-9 are typical of those observed in the upper head penetration nozzles for other nuclear power plants. The stresses are highest in the vicinity of the J-groove weld and decrease rapidly as the distance above the root of the J-groove weld increases.

For the CEDM penetration nozzles where inspection coverage is less than 100% in the region that is 1.25 inch or more above the root of the J-groove weld on the uphill side, the maximum hoop stress for all the CEDM penetration nozzles in that region is about 15 ksi as shown in Figures 1-7. There is nearly universal agreement that high stresses, on the order of the material yield strength, are necessary to initiate Primary Water Stress Corrosion Cracking (PWSCC). There is no known case of stress corrosion cracking of Alloy 600 below the yield stress [2]. Typical yield strengths for wrought Alloy 600 head penetration nozzles are in the range of 37 ksi to 65 ksi. Weld metal yield strengths are generally higher. The yield strength of the CEDM head penetration nozzles for Fort Calhoun varies from 37 ksi to 56 ksi [3]. However, the stress level of 20 ksi has been determined as a value below which PWSCC initiation is extremely unlikely [2]. Since the maximum hoop stress is only 15 ksi in the region where inspection coverage is less than 100%, PWSCC initiation in the region not being inspected is extremely unlikely.

As shown in Figures 1-7, the hoop stresses are highest in the vicinity of the J-groove weld. Since no indications have been detected from 1.25 inch above the J-groove weld to 2.0 inch below the J-groove weld, which included the high stress region in the vicinity of the J-weld, it is unlikely to detect any indications in the low stress region with a maximum hoop stress of only 15 ksi.

Nevertheless, PWSCC crack growth calculation is performed in the region above the J-groove weld that is not being inspected. The purpose of the calculation is to determine the maximum flaw size for an axial inside surface flaw that would grow to 75% of the wall thickness in one fuel cycle (18 months). The methodology used in the crack growth calculation is consistent with the NRC flaw evaluation guidelines for the upper head penetrations [4]. The PWSCC crack growth rate used in the NRC flaw evaluation guidelines is the same as that recommended in MRP-55 Rev. 1 [5]. Assuming an aspect ratio of 6, the crack growth results are shown in Figures 10 and summarized below in Table 1 for both the downhill and uphill side of the two outermost CEDM penetrations.

Table 1

Minimum Flaw Size to Reach 75% of Wall Thickness in One Fuel Cycle
(Aspect Ratio = 6)

	Minimum Flaw Size (% Through-wall)	
CEDM Nozzle Angle (°)	Downhill	Uphill
37.3	68.5	69.1
41.7	68.2	68.6

Based on the results tabulated in Table 1, for an inside axial surface flaw, a minimum initial flaw depth of 0.26 inch (68% part-through wall) is required to reach 75% of the wall thickness in one fuel cycle. For an aspect ratio of 6, the minimum initial flaw length is 1.56 inch long. Due to the low probability of PWSCC initiation in the low stress region that is more than 1.25 inch above the root of the J-groove weld on the uphill side, detection of a 68% part-through wall inside surface flaw with an aspect ratio of 6 in that region is extremely unlikely.

In addition, there is inherent conservatism in the above crack growth results. From Table 5-3 of MRP-55 Rev. 1, the mean crack growth amplitude (α) for each Huntington Alloy 600 heat is summarized below:

Table 2

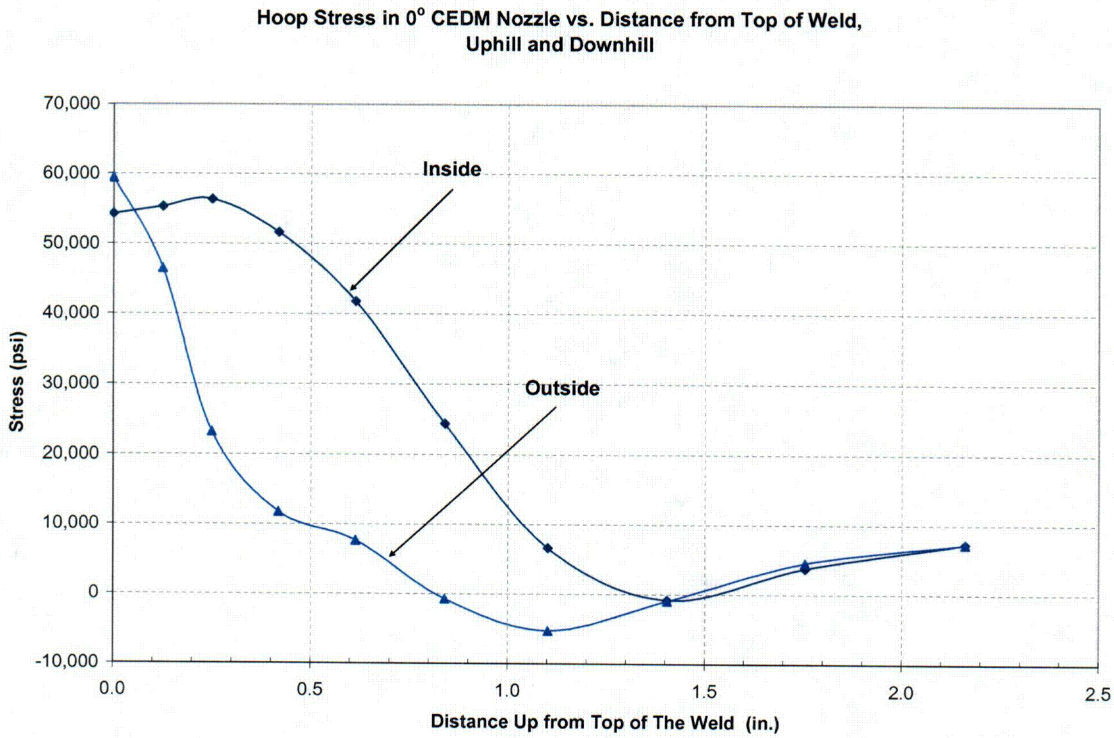
Mean MRP-55 Crack Growth Amplitude (α) for Huntington Material Test Data

Heat	Material Supplier	Mean α (SI units)
NX8101	Huntington	1.37×10^{-12}
NX8664	Huntington	1.29×10^{-12}
NX6420G	Huntington	7.21×10^{-13}
NX9240	Huntington	4.97×10^{-13}
NX8168G	Huntington	1.93×10^{-13}

Huntington is the material supplier for the CEDM penetration nozzles for Fort Calhoun. Since the recommended crack growth amplitude, α, from the NRC flaw evaluation guidelines [4] is 2.67×10^{-12}, the recommended PWSCC crack growth rate is about a factor of 1.9 higher than that obtained from the test data for any of the Huntington material heats.

With respect to the missed inspection coverage for 41.7 Deg CEDM nozzles (Figures 6 and 7) from 1.06" up to 2.0" above the root of the uphill side J-groove weld for 360 Deg around, a review of the hoop stress distribution in this larger area indicated that the hoop stress distribution used previously to determine the crack growth curve for missed inspection coverage from 1.25" to 2.0" above the root of the J-groove weld remains applicable and therefore the resulting crack growth curve is still applicable to this larger area.

Figure 1


Hoop Stress in 0° CEDM Nozzle vs. Distance from Top of Weld,
Uphill and Downhill
Inside
Outside
Stress (psi)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
0.0
0.5
1.0
1.5
2.0
2.5
Distance Up from Top of The Weld (in.)

C34

Figure 2

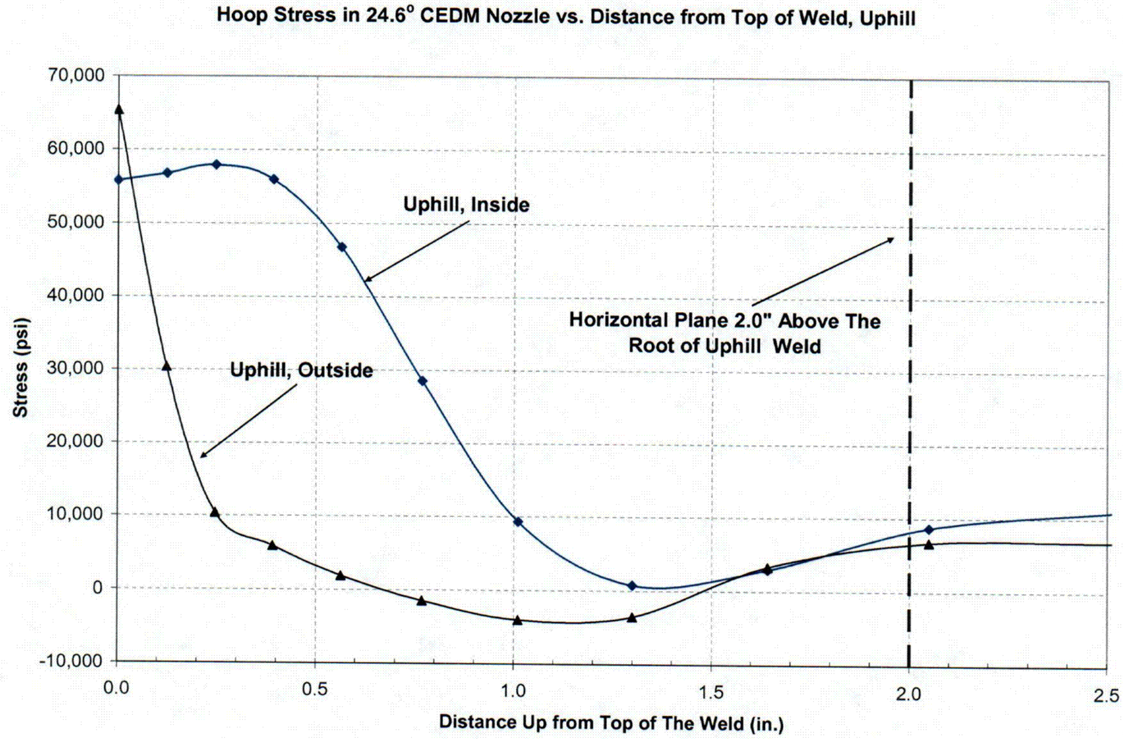
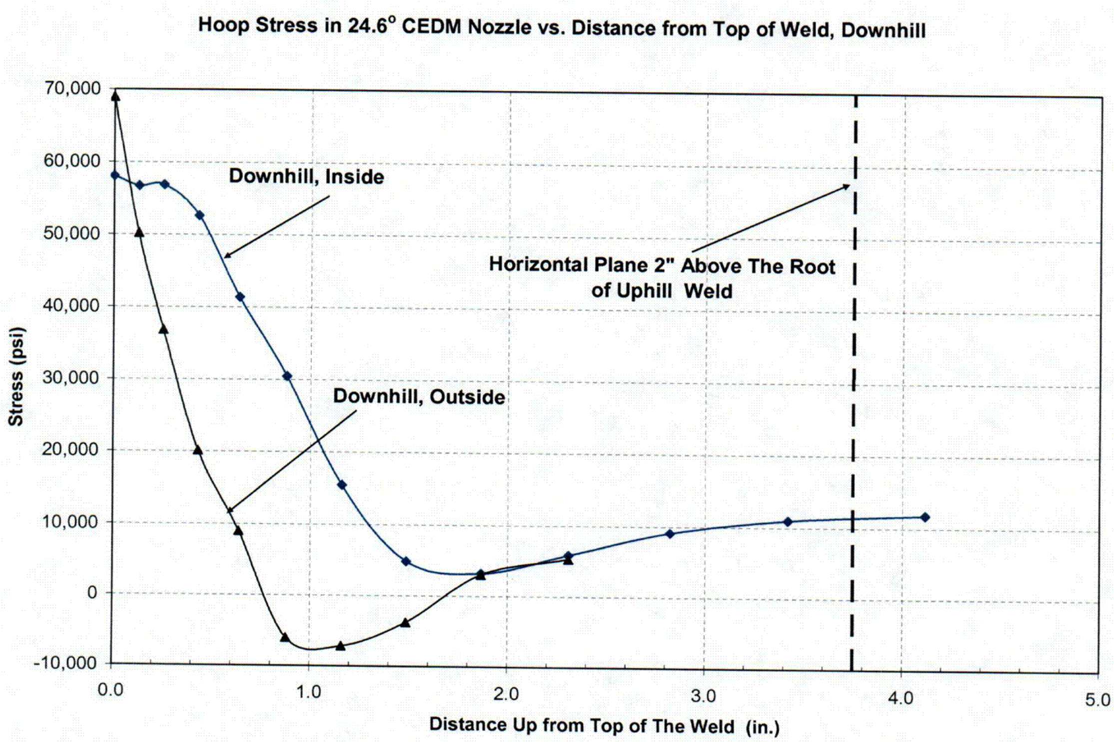


Figure 3



C35

Figure 4

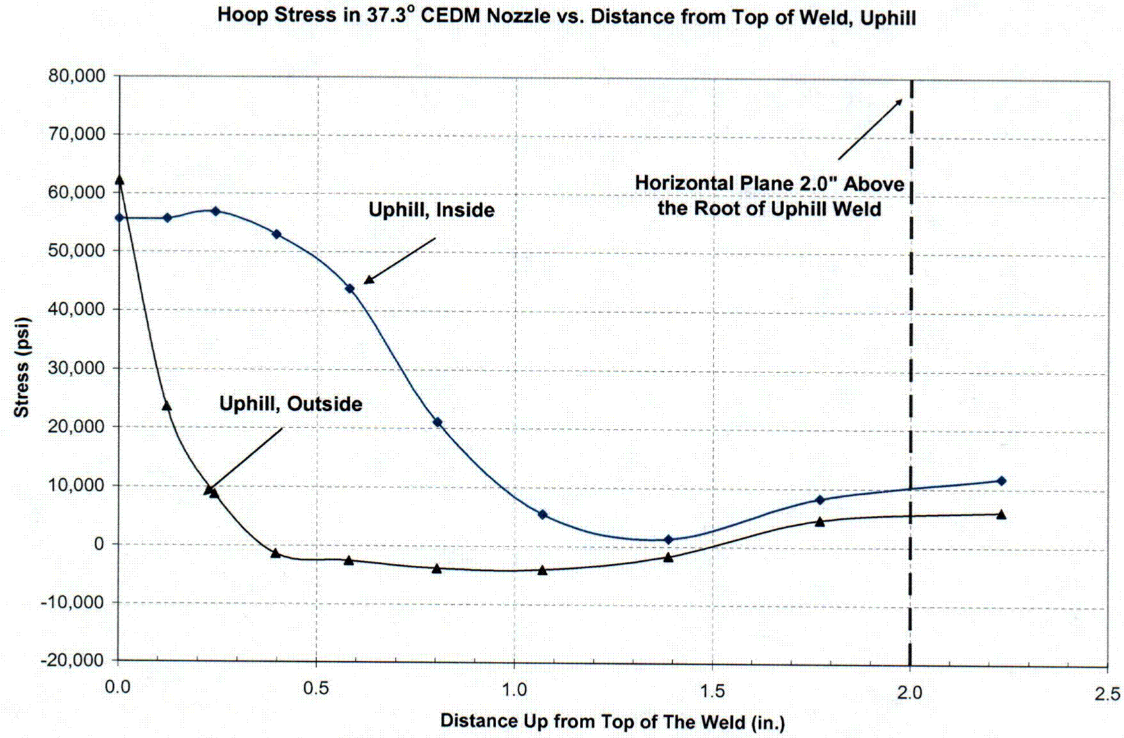
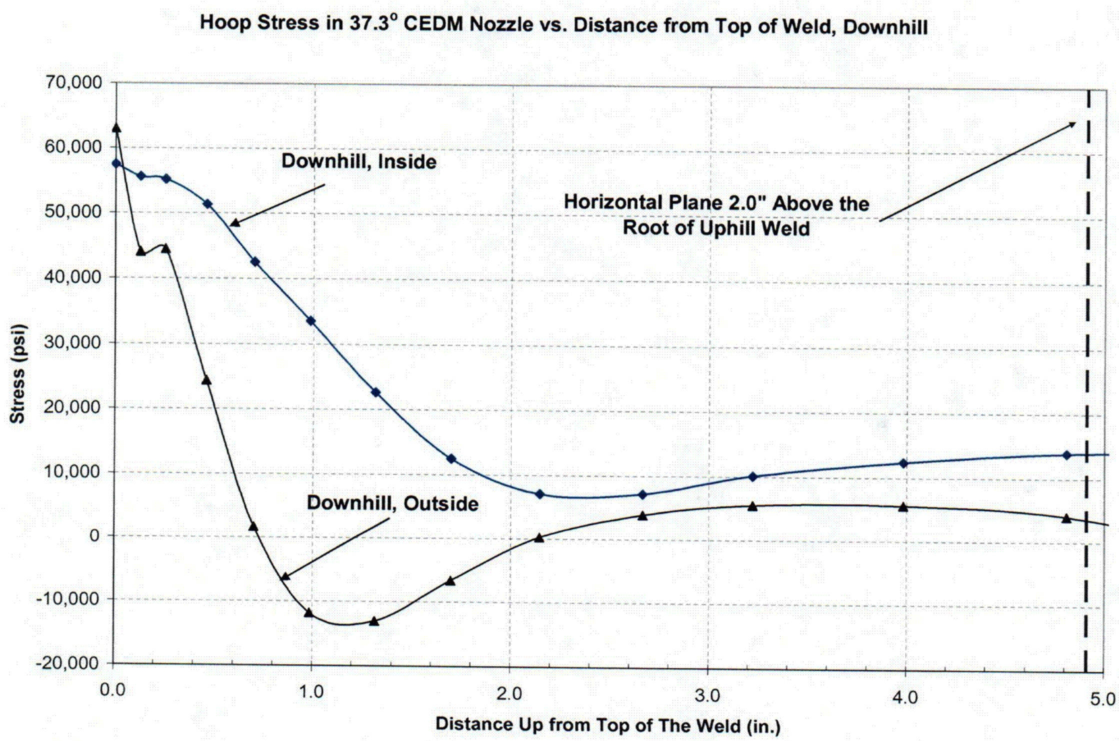


Figure 5



C36

Figure 6

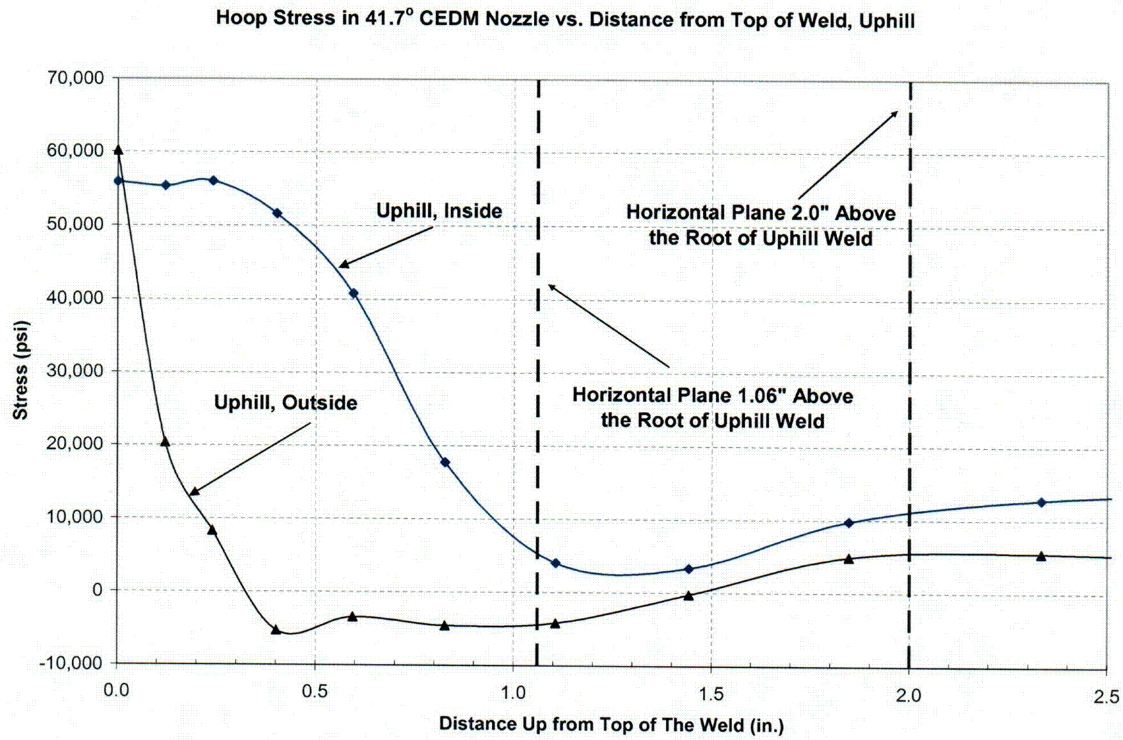
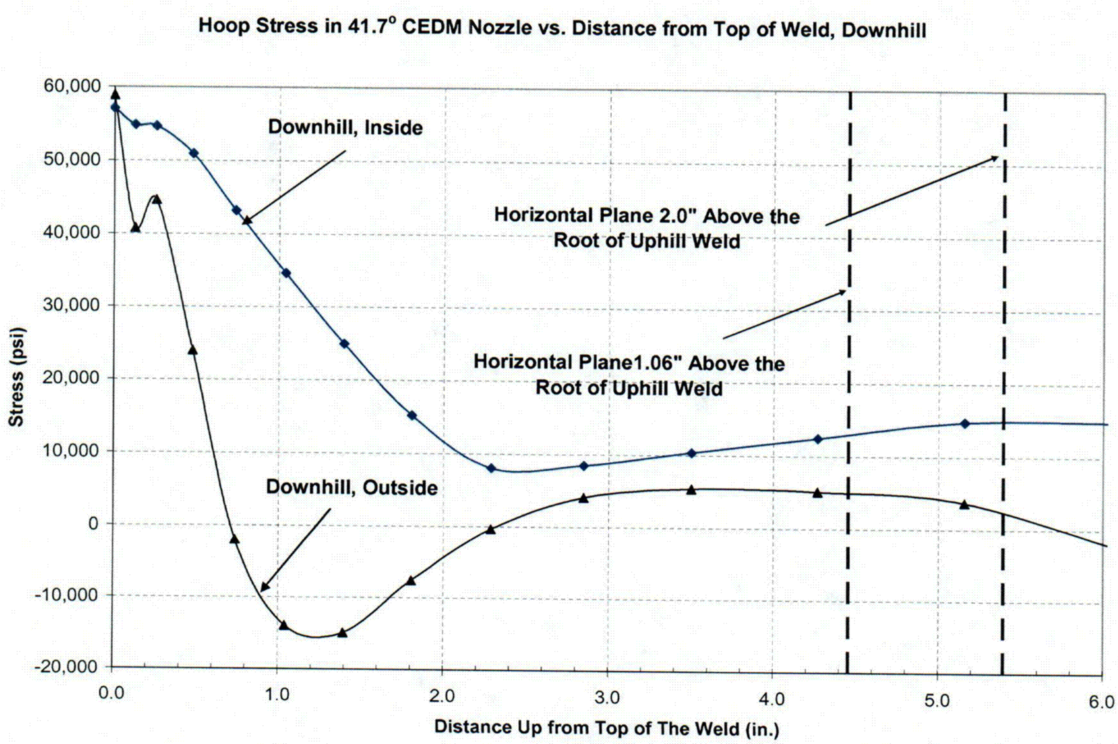


Figure 7



C37

Figure 8

Hoop Stress in 54.4° ICI Nozzle vs. Distance from Top of Weld, Uphill

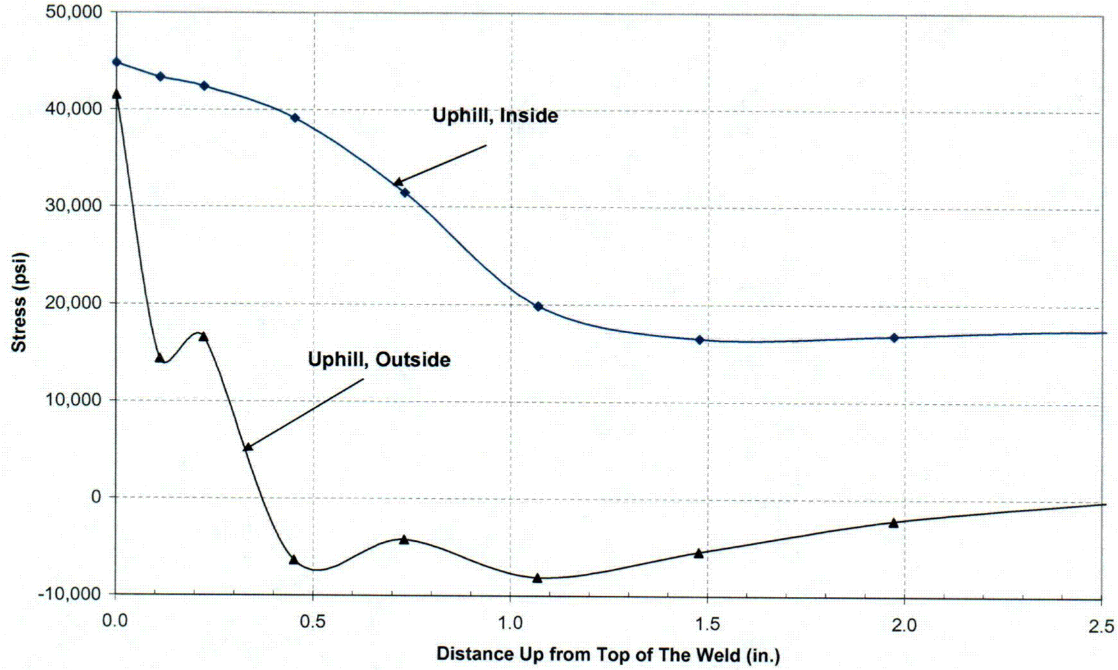
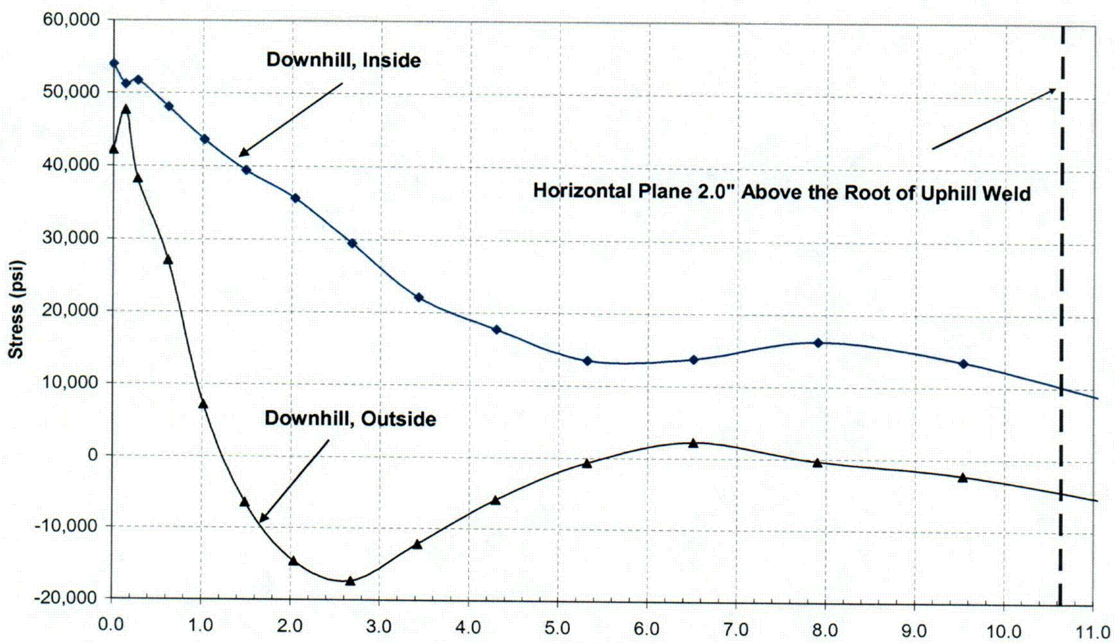


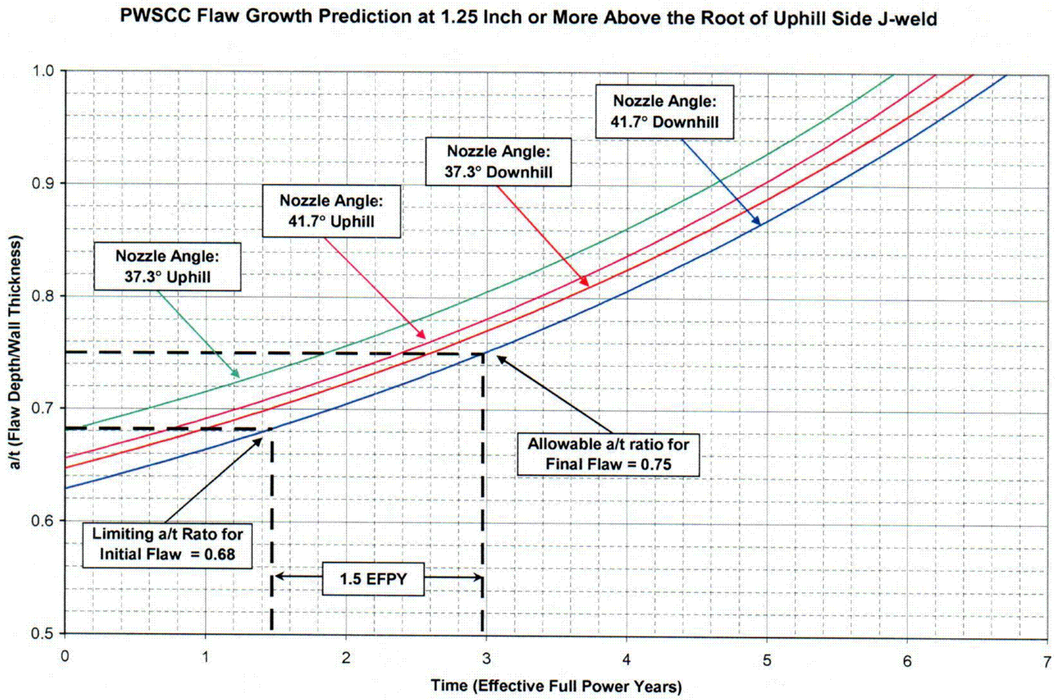
Figure 9

Hoop Stress in 54.4° ICI Nozzle vs. Distance from Top of Weld, Downhill



C38

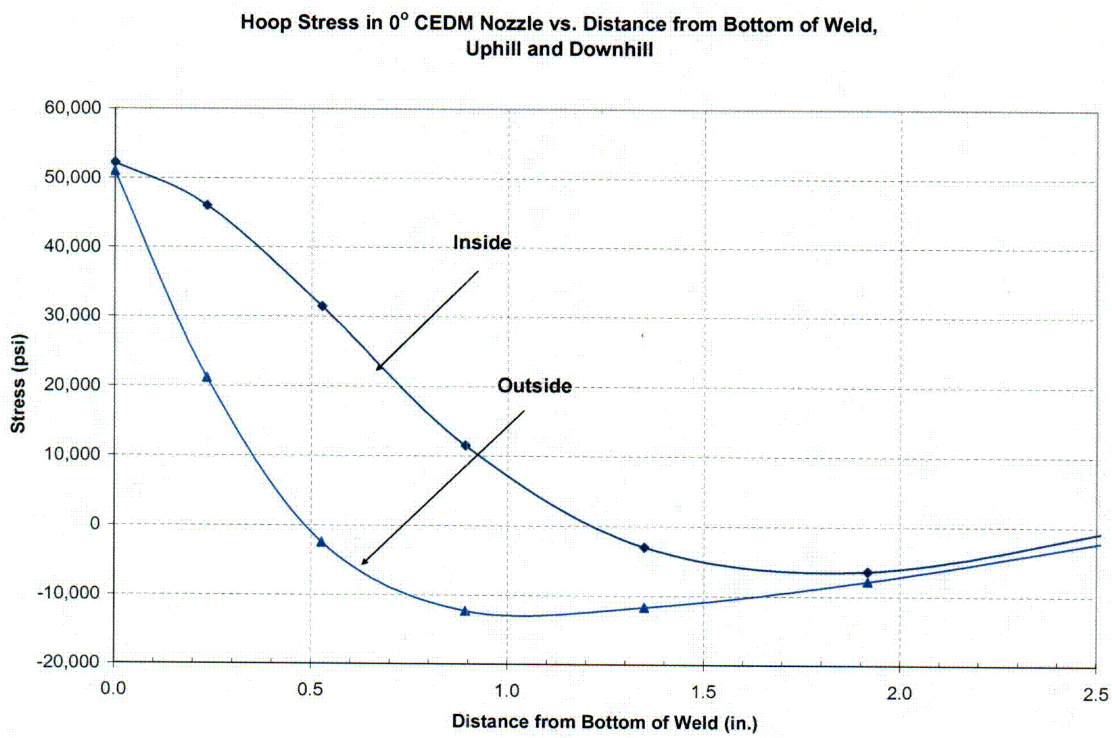
Figure 10


PWSCC Flaw Growth Prediction at 1.25 Inch or More Above the Root of Uphill Side J-weld
Nozzle Angle: 41.7° Downhill
Nozzle Angle: 37.3° Downhill
Nozzle Angle: 41.7° Uphill
Nozzle Angle: 37.3° Uphill
Allowable a/t ratio for Final Flaw = 0.75
Limiting a/t Rato for Initial Flaw = 0.68
1.5 EFPY
a/t (Flaw Depth/Wall Thickness)
1.0
0.9
0.8
0.7
0.6
0.5
0
1
2
3
4
5
6
7
Time (Effective Full Power Years)

3.0 Hoop Stress Distribution Below the Toe of the J-Groove Weld

Figures 11-19 show the hoop stress distributions for the regions that are below the toe of the J-groove weld for the Fort Calhoun reactor vessel upper head penetrations. The stress distributions shown are for the inside and outside surface of the reactor vessel upper head penetrations. The stress distributions shown in Figures 11-19 are typical of those observed in the upper head penetration nozzles for other nuclear power plants. The stresses are highest in the vicinity of the J-groove weld and decrease rapidly as the distance below the toe of the J-groove weld increases. Based on Figures 11-19, the hoop stress for all the penetration nozzles is less than 20 ksi at a distance of 1 inch or more below the toe of the downhill side J-groove weld. Therefore, the inspection requirements given in NRC Order EA-03-009 is met provided inspection coverage of at least 1 inch below the toe of the J-groove weld can be achieved.

Figure 11



C40

Figure 12

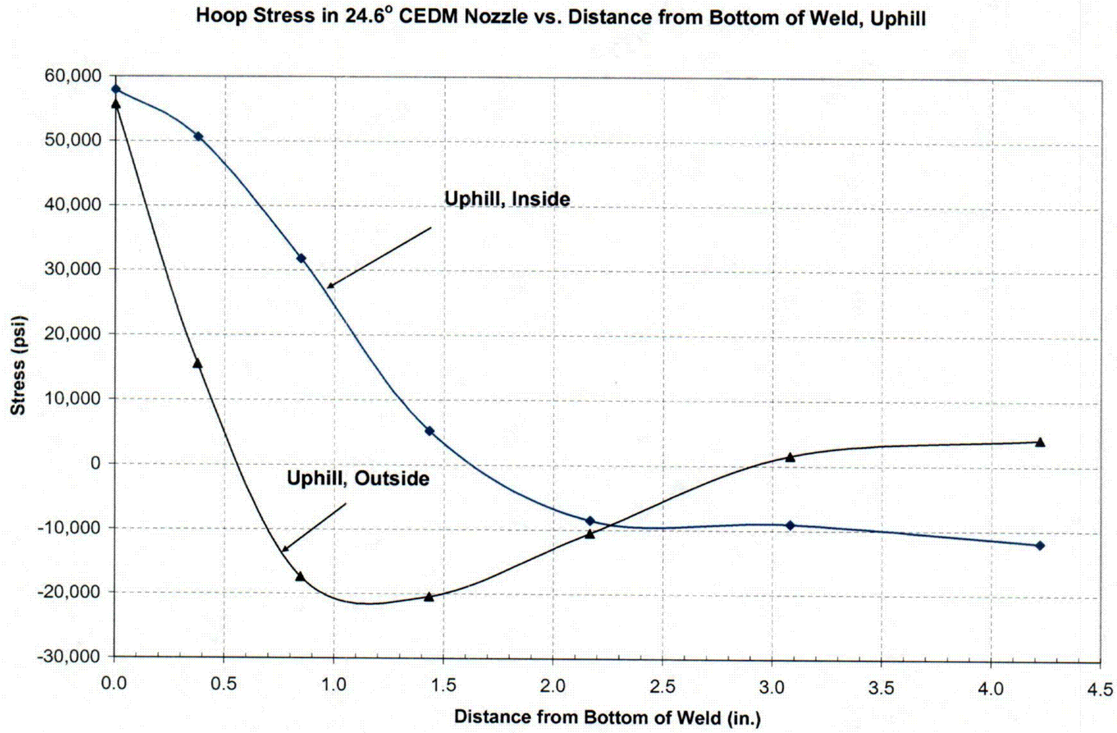
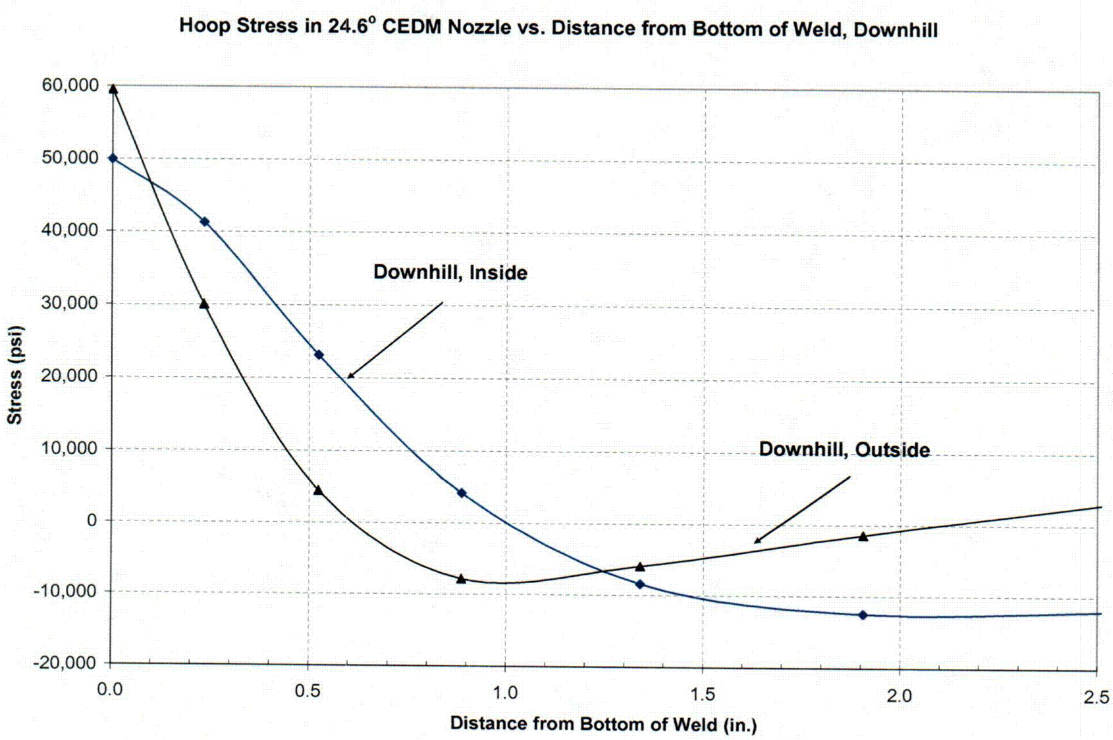


Figure 13



C41

Figure 14

Hoop Stress in 37.3° CEDM Nozzle vs. Distance from Bottom of Weld, Uphill

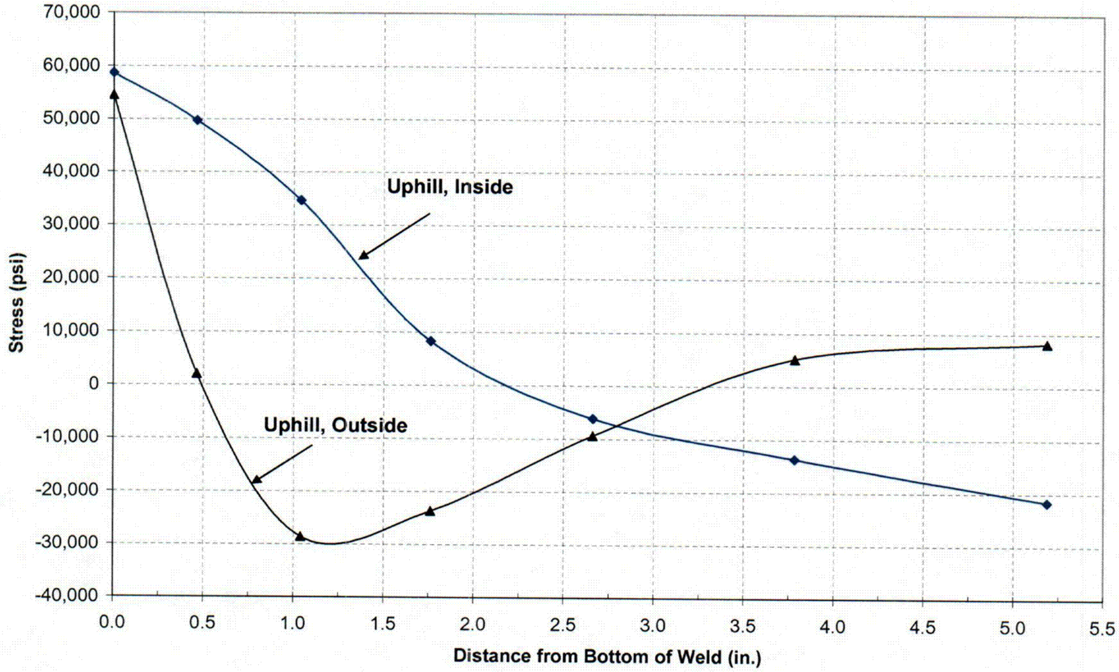
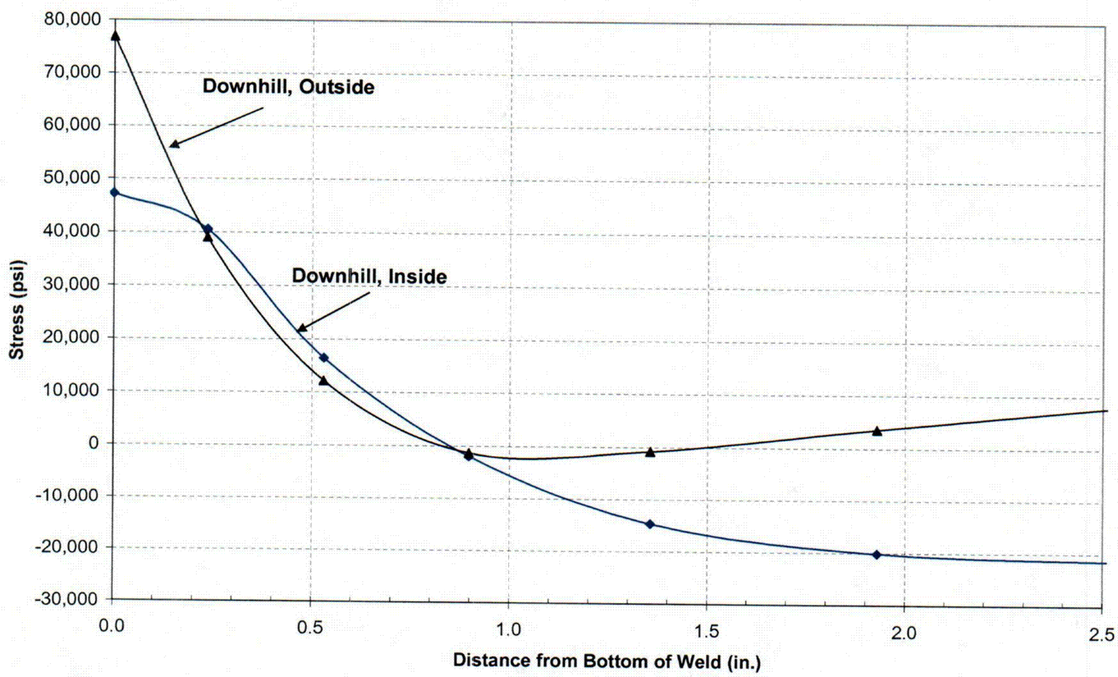


Figure 15

Hoop Stress in 37.3° CEDM Nozzle vs. Distance from Bottom of Weld, Downhill



C42

Figure 16

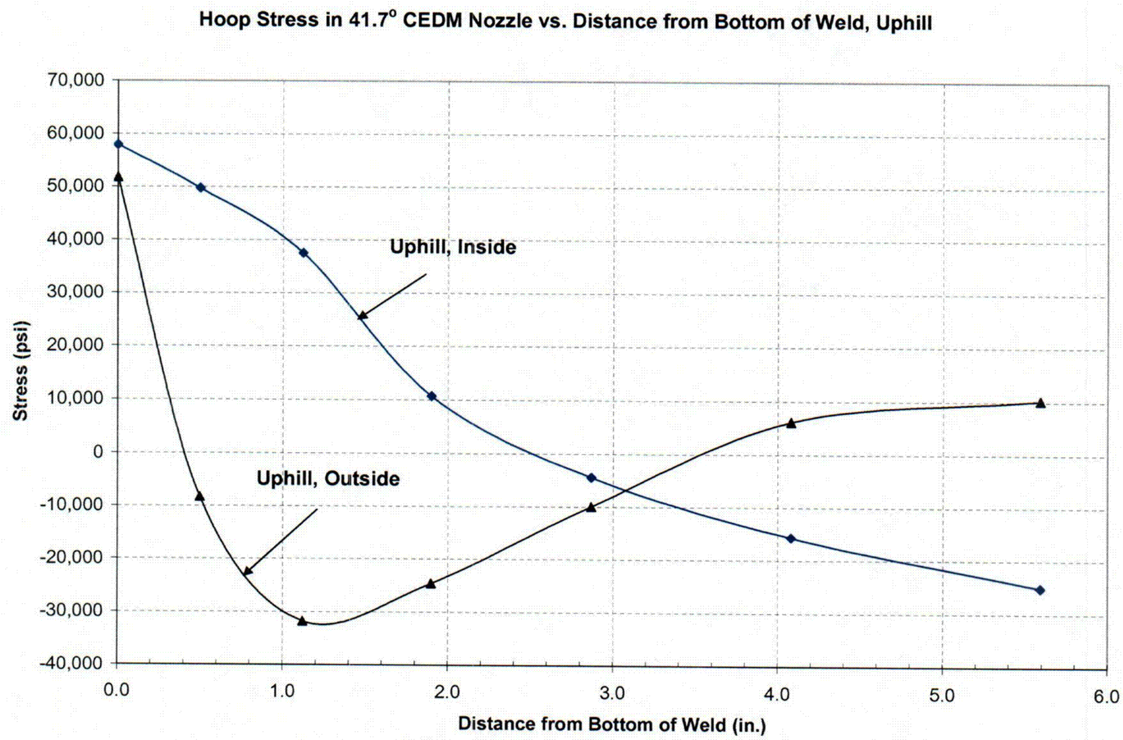
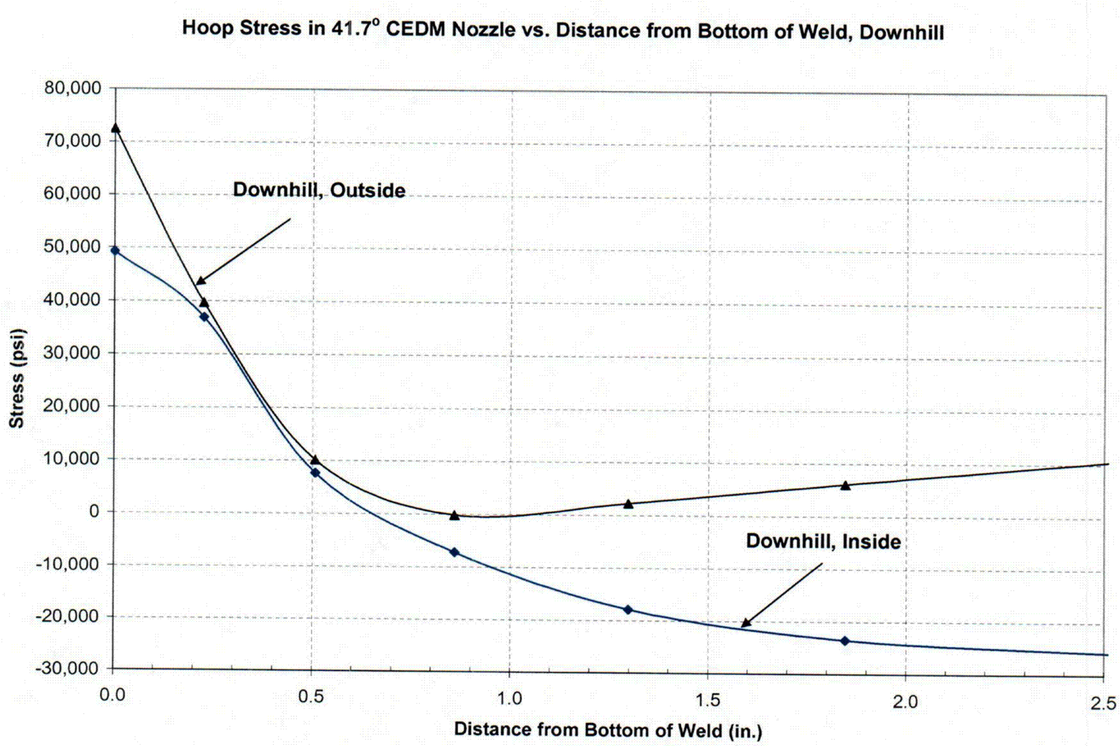


Figure 17



C43

Figure 18

Hoop Stress in 54.4° ICI Nozzle vs. Distance from Bottom of Weld, Uphill

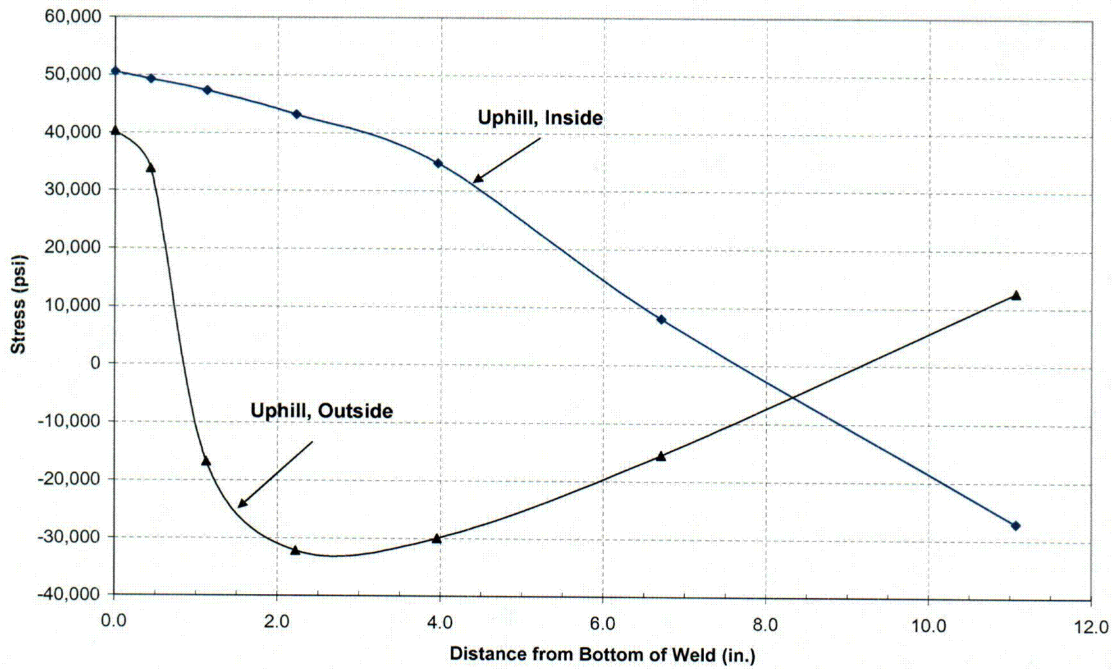
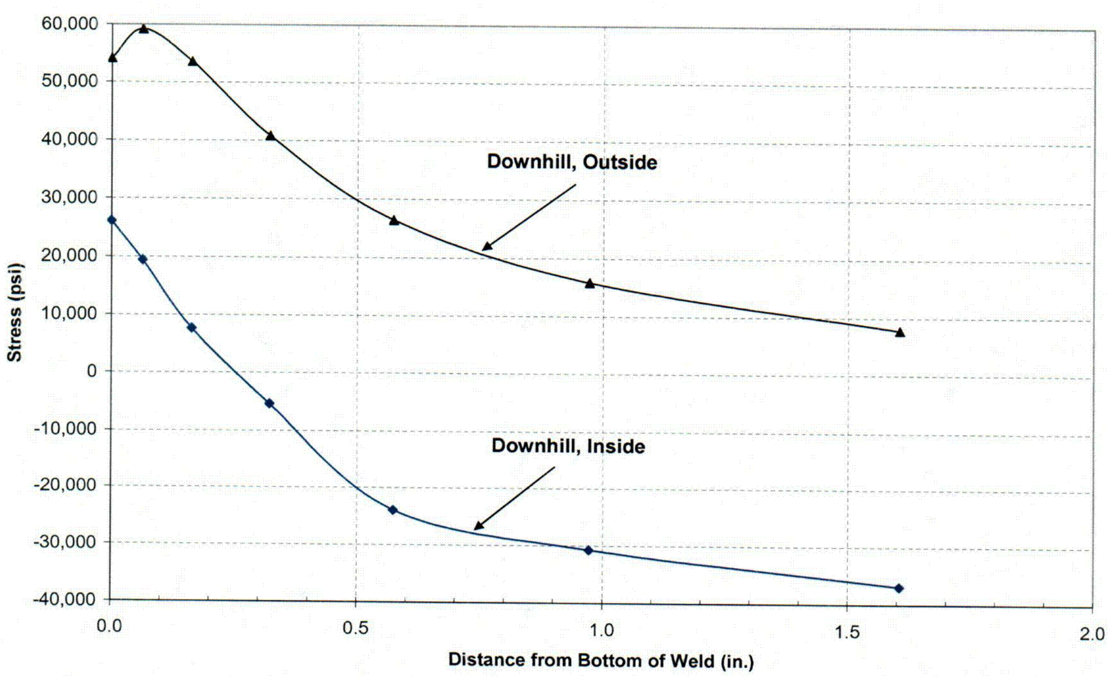


Figure 19

Hoop Stress in 54.4° ICI Nozzle vs. Distance from Bottom of Weld, Downhill

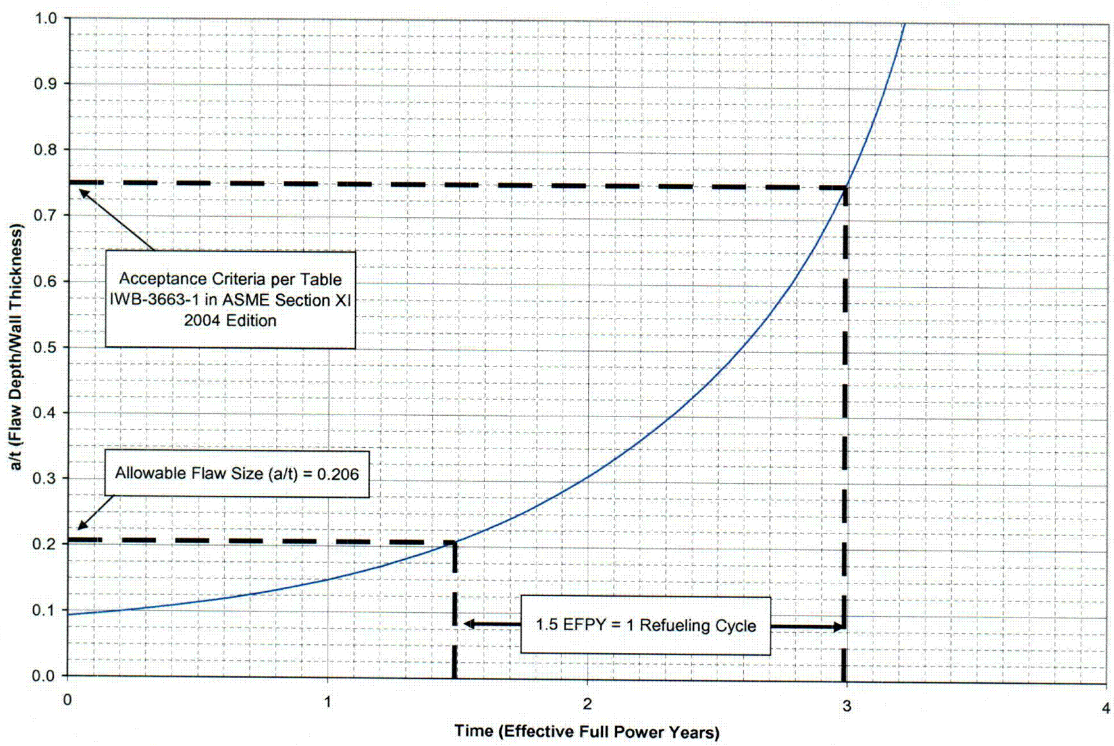


4.0 Flaw Evaluation for Lack of Inspection Coverage on the CEDM Uphill Side

PWSCC crack growth calculation is performed assuming that a portion of the region (2" above the weld to 1" below the weld) on the uphill side of the CEDM nozzles cannot be inspected. The purpose of the calculation is to determine the maximum flaw size for an inside axial surface flaw that would grow to 75% of the wall thickness in one fuel cycle (18 months). The methodology used in the crack growth calculation is the same as that described in Section 3.0, except that the highest hoop stress distribution on the uphill side of the CEDM nozzle is used in the evaluation. Assuming an aspect ratio of 10, the crack growth result for the uphill side of CEDM nozzle angles of 24.6°, 37.3° and 41.7° are shown in Figure 20. Based on the result shown in Figure 20, for an inside axial surface flaw, a minimum initial flaw depth of 0.08 inch (21% part-through wall) is required to reach 75% of the wall thickness in one fuel cycle.

Figure 20

PWSCC Axial Inside Surface Crack Growth Prediction for 24.6°, 37.3° and 41.7° Uphill Side CEDM (Based on Highest Stress Distribution Above, At and Below the Weld)



C45

5.0 Impact of Circumferential Flaws on Inspection Coverage Adequacy

Circumferential flaws located below the weld have no structural significance except that loose parts must be avoided. Since no through-wall circumferential flaws were detected below the weld, there is no concern of loose parts before the next refueling outage.

As shown in Figures 5-3 through 5-7 in Reference 1, the hoop stress in the penetration nozzle at and above the J-groove weld resulting from the steady state operation loadings and welding residual stresses is much higher than the axial stress. Therefore from the leakage consideration point of view, it would take much longer for an inside surface circumferential flaw to propagate through the penetration wall thickness and result in leakage than it would take for an inside surface axial flaw with similar initial flaw size. The crack growth result for an inside axial surface flaw discussed in Section 4.0 is conservative with respect to that for an inside circumferential flaw.

The main concern for a circumferential flaw is that it may result in penetration nozzle ejection. However, this is an unlikely scenario unless it is located above the J-groove weld. The finite element stress analysis results [1] support the safety argument that cracks are unlikely to propagate in the circumferential direction above the J-groove weld because the axial stresses are relatively low. This is illustrated in the stress cuts taken along the plane of the top of the J-groove weld, as shown in Figures 5-8 to 5-12 in Reference 1. It can be seen that a large area of compressive axial stress exists in each penetration nozzle along the plane just above the J-groove weld. In addition, it has been shown that the CEDM penetration nozzles are very tolerant of large circumferential flaws and that the critical through-wall circumferential flaw size based on plastic limit load failure has been determined to be approximately 330-350° [8]. Due to the large area of compressive axial stress above the J-groove weld and the large critical through-wall circumferential flaw size, penetration nozzle ejection is not a likely scenario before the next refueling outage.

Based on a review of the axial stress distributions above the J-groove weld, in order to result in penetration nozzle ejection, a circumferential surface flaw must first become a through-wall flaw and then propagate around the penetration nozzle circumferentially until plastic limit load failure occurs. It is evident then that leakage would occur before penetration nozzle ejection. Since the time required for leakage is more limiting for an axial surface flaw, postulation of circumferential surface flaw in the penetration nozzle is not crucial in determining the inspection coverage adequacy.

6.0 References

1. Dominion Engineering Inc. Task No. 87-18, Calculation No. C-8718-00-1, Revision 0, "Fort Calhoun CEDM and ICI Nozzle Stress Analysis" April 18, 2005.

2. "Materials Reliability Program: Generic Evaluation of Examination Coverage Requirements for Reactor Pressure Vessel Head Penetration Nozzles (MRP-95)," EPRI, Palo Alto, CA: 2003. 1009129.

3. CE NPSD-903-P, CEOG Task 730, "CEOG Program to Address Alloy 600 Cracking of CEDM Penetrations, Subtask 1, Nozzle Evaluation", February 1993.

4. USNRC Letter, R. Barrett to A. Marion, "Flaw Evaluation Guidelines," April 11, 2003.

5. "Materials Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Wall Alloy 600 Material (MRP-55) Revision 1," EPRI, Palo Alto, CA:, November 2002. 1006695.

6. Cloud, R. L., and Palusamy, S. S., "A Summary and Critical Evaluation of Stress Intensity Factor Solutions of Corner Cracks at the Edge of a Hole," WRC Bulletin 276, April 1982.

7. Material Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182 and 132 Welds (MRP-115) 1006696 - 11/02/2004 - 05T041.0

8. CEOG Report # CEN-614, "Safety Evaluation of the Potential for and Consequences of Reactor Vessel Head Penetration Alloy 600 OD Initiated Nozzle Cracking," December 1993.